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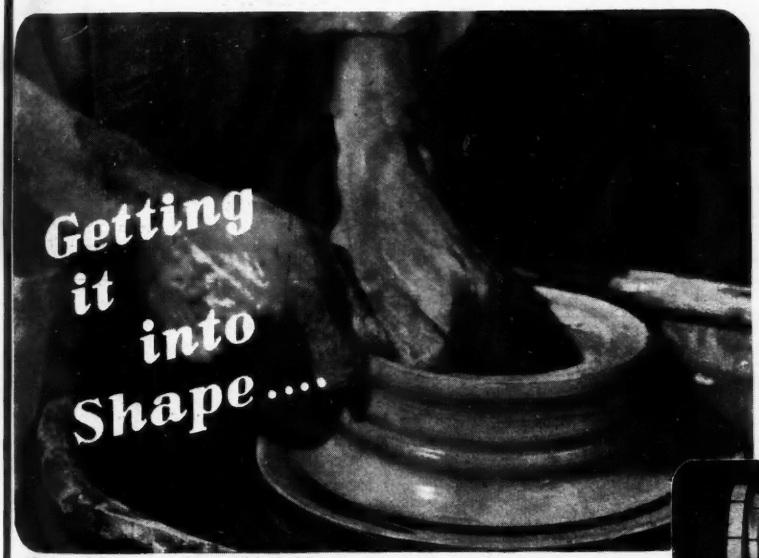

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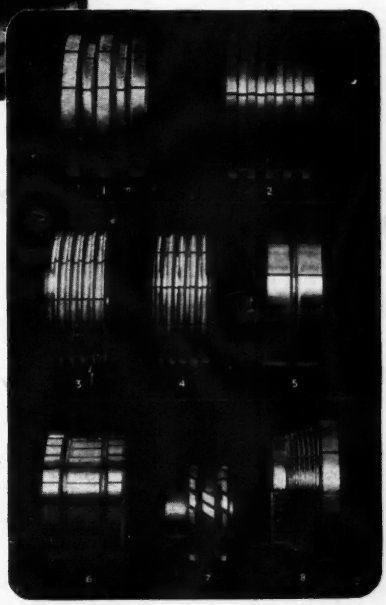

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Application of Supersonics in Industrial Inspection

By J. W. Dice. (From *The Engineers' Digest*, American Edition, Vol. 4, No. 8, August, 1947, pp. 352, 396.)

The desire to " see " into solid objects at greater and greater depths, and definitely determine the position and extent of internal defects without destroying the material in the process has been the motivating influence behind many industrial inspection developments in the past. Internal defects present in the raw material many times meant wasteful losses of labour and material before the defects were discovered and the raw material scrapped. Defects remaining in finished parts, or induced in them by faulty processing, often resulted in sub-standard, unsafe parts being incorporated into machines and equipment where failure meant costly property damage or even loss of life.

Until World War II the only internal inspection methods available to industry were the X-ray, gamma ray, fluoroscope and to a lesser extent, magnetic inspection equipment. All were limited in depth of penetration to a few inches of steel at best. In many cases, extremely small defects in highly stressed parts such as jet and gas turbine rotors could not be picked up with known techniques, yet under service conditions constituted a potential hazard.

During World War II an entirely new method of non-destructive testing, employing supersonic sound waves, was developed by Floyd R. Firestone of the University of Michigan. Although many laboratory experiments had been conducted by leading physicists and scientists in many countries, all in an effort to know more about the production and possible use of supersonic, or high frequency, sound waves, Firestone was the first to discover a practical method of employing such waves for internal inspection. Penetration limitations and difficulty of small defect detection inherent in previous non-destructive testing techniques were overcome by the supersonic sound beam which " sees."

There exists some confusion to-day in that the word " supersonics," as used by the aviation fraternity, means a plane or an object travelling through air at a speed greater than that of audible sound. As applied to inspection and testing in industry, " supersonics " refers to sound waves of a frequency beyond the range of hearing of a normal ear. Since the top limit of the audible range is approximately 18,000 cycles per second, sounds of a higher frequency (shorter wavelength) are considered to be supersonic.

Supersonic sound waves are easily generated at frequencies up to several million cycles per second by impressing the electrical output of an electronic pulse generator upon a piezo-electric crystal transducer. This transducer converts the pulse energy into a mechanical vibration at the face of the crystal. Thus an electrical frequency, of say one megacycle, impressed on the crystal results in the emanation of a one mc. supersonic sound beam from the crystal face into the material to be tested. The action of the crystal transducer is reversible and supersonic waves received by it can be converted into electrical energy. The beam is highly directional. Wave velocity depends on Young's modulus and Poisson's ratio of the material tested. Speed of transmission of the waves through solids is considerably greater than through air, for example, in steel or aluminium the vibration wave travels approximately twenty times faster.

Two basic testing techniques are in use in industry to-day. The first, or " through transmission " method employs two transducers, one to send the supersonic vibration into the test piece and the other to receive the transmitted vibration as it emerges from the other side of the piece. If a mechanical discontinuity such as a void, crack, lamination or inclusion is present, part of the sound beam will be blocked and the receiver crystal will pick up only the energy transmitted through the good material surrounding the defect. This unbalance between energy sent and energy received is made to operate a sensitive signalling device. Typical industrial applications are the testing of sheet steel for laminations and bonded bimetals for lack of bond. With this method it is customary to immerse the test piece and the transducers in an oil or water bath.

The second basic testing technique, the " reflection " method, is the one which has had wide acceptance in American Industry. The instrument used is known as a Reflectoscope. The principle of operation of the Reflectoscope is that it sends supersonic vibrations through the material under test and measures the length of time it takes these vibrations to penetrate the material, reflect from the opposite side, or an internal defect, and return to the sending point. The same transducer acts both as a sender and as a receiver of these supersonic vibrations. The pulse generator section of the Reflectoscope transmits through the crystal transducer, a short burst of sound energy lasting a few microseconds. The crystal then stops oscillating and is ready to receive reflected vibrations from internal defects for conversion back into electrical energy. Timer circuits are set so that this cycle is repeated sixty times per second. Transmitted and reflected pulses form a pattern on a large oscilloscope screen which enables the operator to read directly the exact depth of the defect from the testing surface and its approximate size. By moving the transducer over the surface of the material, the entire interior may be rapidly scanned for defects. For example, a shaft or axle may be searched merely by applying the transducer to one end.

Supersonic inspection and test is readily adaptable to the two broad categories of industrial test needs—(1) inspection of materials during production and fabrication, and (2) inspection for fatigue cracks which may develop in vital parts of machinery and equipment under service conditions.

In the field of production testing, one of the first applications of the method was in the inspection of forged jet rotor blanks and turbo supercharger rotors for minute voids and cracks. Since the initial applications on aircraft parts, supersonic testing has been used successfully on many classes of materials. Several typical examples are :

Steel :—	Ingots, Billets, Blooms, Axles, Castings, Die Blocks, Forgings, Gas Turbine Rotors, Gears, Plate, Propellers, Tool Steels, Work Rolls.
Aluminium :—	Billets, Blooms, Castings, Wing Spars.
Magnesium :—	Castings, Extruded Shapes.
Plastics :—	Vinylite, Catalin, Bakelite, Lucite and Plexiglass sheets and shapes.
Brass and Bronze :—	Forgings, Extrusions.

Other Materials, such as wood, nickel, molybdenum, sintered carbides, tungsten, platinum and the precious metals have been tested in small quantities.

In the second category of industrial inspection—that of testing for fatigue cracks—wide use of the method has been made. A few such tests are given in the following table :

Job No.	Product of Plant	Equipment Tested	Parts Tested	Maximum Dimensions	Result of Test
1	Paper Boxes	Steam Engine	2 Shafts and 1 Piston Rod	18·5 ft. long	Small crack on one shaft.
2	Film	Ammonia Compressors	40 Shafts and Piston Rods	21 in. dia., 15 ft. long	Located cracks in two shafts.
3	Paper Board	Power Plant	2 Shafts	16 in. dia., 9 ft. long	No indications of cracks.
4	Pencils	Power Plant	1 Shaft	10 ft. 6 in. long	Small reflections—no cracks
5	Gas	Compressors	Shafts, Pins and Bolts	9 ft. 6 in. long	No indications of cracks
6	Hotel	Power Plant	1 Shaft	9 ft. long	No indication of cracks.
7	Brass	Press	Cast Steel Cylinder	9 ft. dia	Tested extent of crack prior to repairing.
8	Chemicals	Pressure Vessels	Reactor and Separator Tubes	3½ in. wall, 17 ft. long	Forged steel—no indications of defects.
9	Electricity	Diesel Engine	Crankshaft	19½ in. dia.	Tested cracked journal to determine extent of crack.
10	Sugar	Diffuser	48 Shafts	14 ft. long	No cracks located.
11	Oil	Pressure Vessel	Side and Heads	72 in. dia., 91 ft. long	Traced areas of small inclusions and location in 5 in. plate.
12	Steel Sheet	Rolling Mill	4 Work and Back-up Rolls	15½ ft. long	Located crack in one roll 18 in. from end.
13	Cement	Kiln	4 Tyres	12½ ft. dia.	Traced out cracks in weld of welded tyres.
14	Paper	Paper Machinery	Yankee Dryer and Pressure Rolls	186 in. wide	Located cracks in both ends of pressure roll and porosity in dryer.
15	Ships	Stern Frame	Skeg	20 in. wide	Located shrinkage and porous area.
16	Sheet Aluminium	Rolling Mill	Work Rolls	15 ft. long	Traced out depth of visible crack—no others.
17	Aluminium	Extrusion Press	Columns	16 in. dia., 24 ft. long	Located small cracks in column.
18	Electricity	Turbine	83 Hold Down Studs	Up to 5 in. × 52 in. long	Tested for cracks—none located.
19	Plastics	Shredders	9 — Rolls	18 in. dia., 62 in. long	No cracks but poor transmission in one.
20	Forgings	Forging Press	Piston Rods	12 ft. long	Located cracks near hammer end.

Experience to date has demonstrated that supersonic testing represents a distinct advance in the art of inspection. The great depth of penetration, the ability to find minute flaws heretofore impossible to locate by other methods, the ease and rapidity of testing, have reduced wasteful losses of materials and machine-hours in the processing and fabricating industries. The application of supersonic testing to vital parts of installed equipment, without any disassembly of the equipment in many cases, is contributing much toward greater operating safety as simple routine checks for fatigue crack growth can now be made.

There is no doubt but that untapped application possibilities and the development of additional test methods will extend the use of supersonic testing by industry. In addition to the through-transmission and reflection methods described, much work is now being done on certain variations such as resonant testing, sound absorption and others. The art has shed its swaddling clothes and is now a lusty youngster with a most promising future.

U.S.A.

Roll Oil Emulsion for Cold Strip Rolling

By R. W. Piper. (From *Iron and Steel Engineer*, Vol. 24, No. 7, July, 1947, pp. 62-64.)

The importance of using a good lubricant as a roll oil in cold rolling of strip steel is well known. It is the finding among operating men that the use and application of proper roll lubricants is of utmost importance for good rolling results. For the past thirteen or fourteen years, emulsions have been used increasingly for this important application, replacing such materials as palm oil, light viscosity mineral oil and mineral oil containing additives.

As a basis for discussion of this subject, let us consider a modern four high reversing mill, rolling tin-plate stock using an oil emulsion as a roll oil or roll lubricant. This unit is representative of several such installations in the industry, it being a 42 in. mill having 54 in. diameter backup rolls and 16 in. work rolls; the roll lubricant being supplied from a 5,000 U.S. gallon capacity central system, which system is equipped with twin basket type strainers, coolers, heaters and circulating pump. The pump has a capacity of some 1,800 gallons per minute at 90 pounds pressure with relief valves to provide 40 to 50 pounds maximum pressure at the spray manifolds. The spray manifolds are located at the rolls, and are adjustable for angularity, made of ¾ in. brass pipe nipples flattened to ¼ in. at the opening.

The roll oil emulsion should be a mixture of 25 per cent oil and 75 per cent water. In the event the oil content goes below 20 per cent, more oil must be added. Should the oil content go over 30 per cent then water must be added. Where the oil content is too low, reduction is difficult, resulting in excessive heat from insufficient lubrication. Too rich a mixture is too heavy in viscosity and can produce the same results as too lean a mixture. In other words, too lean a mixture or too rich a mixture can give the same results, namely excessive heats, too much roll crown, undue screw-down pressures, roll strain, etc.

In cold rolling of strip steel, it is important to make complete use of the coolers and heaters in the roll oil system which have a control range of 90 to 120 deg. F. and which under general operating conditions are set for 100 to 110 deg. F. Roll contour is controlled by sprays of roll oil emulsion to the backup rolls. The pressure of the emulsion at the spray manifolds should be definitely controlled as heretofore mentioned, for the reason that improper roll oil pressures can cause heat streaks on the rolls, resulting in unnecessary roll polishing and delays, all of which can be eliminated by proper control of spray nozzle pressures.

Under the described conditions when rolling tin-plate stock using roll oil emulsions exclusively as a roll lubricant, the average reductions and rolling speeds are as follows: beginning with hot roll strip 0·075, No. 1 pass of 39 per cent reduction to 0·046 at 1,000 ft./min., No. 2 pass of 35 per cent reduction to 0·030 at 1,300 ft./min., No. 3 pass of 33 per cent reduction to 0·020 at 1,500 ft./min., No. 4 pass of 30 per cent reduction to 0·014 at 1,600 ft./min., and No. 5 pass of 29 per cent reduction to 0·010 at 1,600 ft./min. We all agree that these reductions and speeds are considered good practice for any roll lubricant. Under operating conditions as mentioned, it is usually necessary to add approximately 100 gallons of water to the central system for each hour of operation to replace that lost by evaporation. Very seldom is it necessary to add oil, except of course, the small amount of oil emulsion that is on the hot rolled strip as it enters the mill to be cold rolled. This raw oil emulsion is placed on the strip at the hot mill after pickle and is intended to act as an anti-rust slushing compound or medium for the strip while in transit to the cold mill.

It is always good practice to drain and refill the roll oil emulsion system every six weeks of operation, during which period of time as much as 80,000 gallons of make-up water has been added to the original 4,000 gallons required for the initial fill.

The emulsion should be as free as possible from foreign materials, oil or grease. It is important therefore, that maintenance control of mill equipment be strict with the view in mind of protecting oil emulsion systems from foreign materials, oil and grease as much as it is possible to do so.

In this connection, most mills are equipped with piston type pumps on the work roll balancer hydraulic system, in which case the roll oil emulsion from the central system can be used as a hydraulic medium for this balance hydraulic system, thus eliminating one of the main sources of contamination to the roll oil system when changing work rolls.

Roll oil emulsions have also been used with a great deal of success for the cold rolling of high alloys, silicon, stainless, etc., on somewhat the same type of mill as used for tin plate. However reductions and speeds are not as good as when rolling tin-plate stock. In a few cases, emulsion is used on alloys only for breakdown passes. When using roll oil emulsion on alloys, it is necessary to direct the nozzles or sprays to the rolls only, keeping the same away from the strip as much as possible, in order to allow for some heat build-up in the strip being rolled, this being required to obtain elongation of such alloy strip in rolling. The concentration in the emulsions when rolling alloys, silicons, etc., is much less than when rolling tin plate. Good results are often obtained by using 5 per cent oil and 95 per cent water.

Treatment of water supply used in any emulsion is recommended, and particularly in the rolling of alloys it is necessary. In fact it is a must for good results. The water should be treated the same as would be considered good practice for treatment of boiler feed water. Chlorinated treated water should not be used for making emulsions when rolling alloys containing nickel or chrome as chlorine may form metallic soaps, thus resulting in poor roll life.

In the application of roll oil emulsion for cold strip rolling, it is essential that certain working data be known such as, condition of strip surface to be rolled, analysis of water supply, approximate amount and type of foreign oil or grease present, also cleaning of strip after rolling. The surface condition of the strip to be rolled and the water supply to be used are very important due to the high water evaporation conditions.

We speak of emulsions, rather than soluble oils as commonly referred to in industry. Virtually all emulsions used for cold rolling of strip steel use water as a dilute soap solution in the outer phase, in other words, a globule of oil surrounded with water. The suspended substance in the emulsion may be almost any oily material such as sodium, potassium soaps from animal or vegetable fatty acids, naphthenic fatty acids, petroleum sulphonates, etc. The relation of soap to fatty acids is often regarded as a control for a given emulsion. In general, the petroleum sulphonate type of emulsion is best when used as roll oil because of its availability and low cost.

Recently, improved results have been obtained, particularly on high alloys using emulsions made with extreme pressure additives and metal wetting agents; however, complete and definite data is not yet available as it is yet in an experimental stage. Petroleum sulphonate type emulsion is usually made up of 4 to 6 per cent emulsifier, approximately 1 per cent moisture, a small amount of emulsifier passivator, and the remainder a light viscosity mineral oil as a carrier. It is the general consensus of opinion that the value of any emulsion is based on the type of emulsifier used, the light mineral oil being only a carrier for the emulsifier.

Roll oil emulsions should be applied and pressures maintained under the same strict conditions as would apply to any good central lubricating system. After all, the emulsion is the roll lubricant and should be treated as such. The opinion held by some, that is of adding highly oxidized used mineral oil or so-called red engine oil to an emulsion is, in the opinion of lubricating engineers, incorrect. It might be that these additions would help in the case of an emulsion that was made and used immediately; however, it has been found to be very important to allow emulsions, after being mixed, to remain dormant for several hours before using in order that the hydrolysis cycle be completed. If the pH value of an emulsion is checked at the time of mixing, then rechecked several hours later, it will be found that this chemical reaction will have taken place. It is good practice to always try to maintain a pH of 7·5 to 9 on any emulsion in the operating system.

In this paper I have endeavoured to quote facts and statistics regarding the use of roll oil emulsions in actual working conditions and under sound established practice. I realize that this subject can be treated from various angles of operating conditions and opinions but I trust that the information given herein may be helpful, and in some small way contribute to a better understanding of the subject.

In the ensuing discussion the author was asked to define what he understood under highly oxidised mineral oils and to elaborate a little further on his statement referring to the use of these oils. His answer can be summarised as follows: The experience and the theory has been that operators would get excess screwdown pressures, excess reel tension, until they added some red oil, red engine oil, ordinary oil and highly oxidised oil. It was the theory at one plant that the emulsion had to be loaded with lead base grease or some type grease. We believe from our tests that we have observed that the highly oxidised oil, red engine oil, etc., did help on freshly made emulsion. I believe most men familiar with the subject will advise mixing emulsion and not using the same for several hours afterwards. Too high a pH value, say over 10, causes strip breaking. The same applies to using emulsions for wet drawing steel through dies. It now appears the general concensus of opinion that adding red engine oil or highly oxidised mineral oil to a roll oil emulsion is detrimental not only to best rolling oil results, but for cleaning as well. All cold rolled strip invariably has to be cleaned, whether it is electroplated or lithographed, etc. Therefore the good cleaning is important for efficient overall operation. I consider as a highly oxidised mineral oil in reference to this case any oil of 100 second viscosity at 100 deg. F. having a Conradson carbon of over 0·08 or a neutralization number of 0·2 to be in this classification.

RUSSIA

Plastic Deformation and Failure of Polycrystalline Metals Subjected to Strain

By V. S. Averkiev, G. N. Kolesnikov, V. A. Pavlov and M. V. Yakutovitch. (From *Journal of Technical Physics*, Vol. 16, No. 11, 1946, pp. 1349-1356, 10 illustrations.)

The authors describe the design of a machine for the strain testing of small test pieces in the shape of wires over a temperature range from — 195 deg. C. to 850 deg. C. The test temperature was kept constant at the desired level by means of a thermostat. This machine makes it possible to determine the relationship obtaining between stress and strain, i.e., tensile stress and elongation at constant temperature and constant speed of straining. It is equipped for automatic registration of the stress-strain diagram.

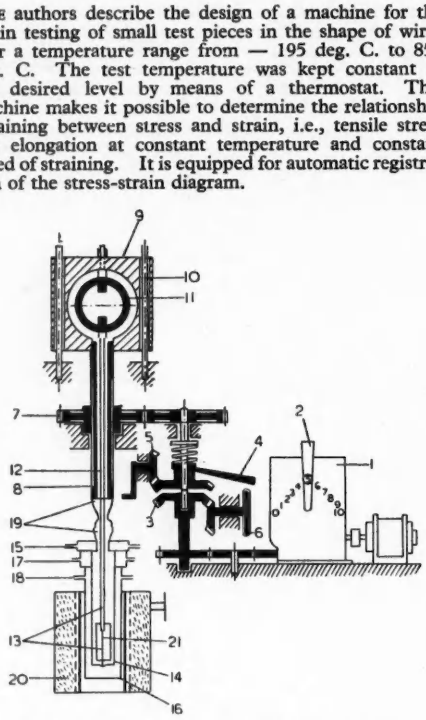


Fig. 1. Diagrammatic arrangement of machine.

Referring to Fig. 1, a three-phase synchronous motor of 0·1 kW is coupled with the change gear box 1 by means of a flexible rubber coupling. The ten different speeds obtainable from the change gear box by manipulating lever 2 cover a speed range from $2 \cdot 10^{-5}$ cm/sec. to $6{\cdot}4 \cdot 10^{-1}$ cm/sec. The driving mechanism is seen to include a friction clutch 3 and a gear-driven nut 7 engaging the travelling hollow screw 8. The friction clutch 3 is operated by the lever 4. When the clutch is disengaged, the travelling screw 8 can be lowered or raised by turning the handle of the drive 5 engaging the upper part of the friction clutch. The manual drive 6 is used for accelerating the engagement of the gear box at low speeds. The driving nut 7, by acting upon the screw 8, raises or lowers the head 9 of the machine, the head being guided by the pillars 10. The interior of the head of the machine contains the ring-type stress gauge 11 to the bottom part of which the rod 12 is attached. This rod passes through the base plate of the machine and extends into the tube 14, the upper grip 13 being attached to its end. The lower grip is bolted to the bottom of the tube 14 the upper end of which is affixed to the underside of the base plate. Both the grips and the tube 14 are made of heat resisting steel ; the upper end of the tube 14 is water-cooled by means of the jacket 15. The test specimen 21, which may be a piece of wire or a thin metal strip, is held in stainless steel clamps inserted into the grips of the machine.

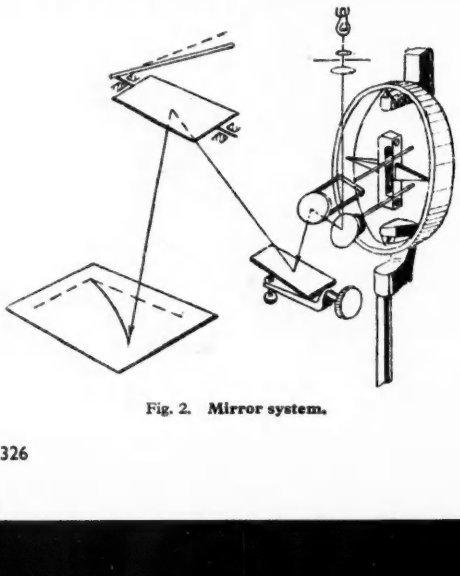


Fig. 2. Mirror system.

The mirror system employed to register the indication of the stress gauge on a photographic plate (13× 18 cm.) is outlined in Fig. 2. Different stress gauge rings may be inserted according to the load range to be applied. In the case of the lowest load range, covering 0 — 5 kg, 1 mm. of the stress scale will correspond with 0·05 kg. loading, while in the case of the maximum load range of 0 — 62 kg, 1 mm. of the stress scale corresponds with 0·6 kg. load. Provision is made for the use of three different strain scales, 1 mm. of the diagram scale corresponding with either $1{\cdot}85 \cdot 10^{-5}$, $7{\cdot}82 \cdot 10^{-3}$, or $2{\cdot}36 \cdot 10^{-2}$ cm.

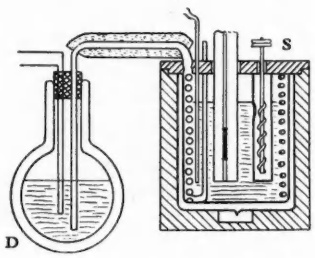


Fig. 3. Cryostat arrangement.

Tests at elevated temperature are carried out with the employment of the furnace 20 (Fig. 1), the temperature of which is controlled by a thermostat. For low temperature tests the furnace is replaced by a cryostat as shown in Fig. 3. This device consists of a wooden cylindrical container with lid which contains a Dewar-vessel filled with aviation benzine. A stream of liquid nitrogen is passed through the copper coil contained in the vessel, the nitrogen being supplied from another Dewar-flask D. The delivery of nitrogen from the latter is caused by vapour pressure induced by an electric heating coil which is under thermostatic control. Temperatures as low as — 130 deg. C. can be obtained with this device ; uniformity of temperature is assured by the stirrer S driven by a small motor.

Standards of Human Comfort

By M. HOTTINGER. (From *Schweizerische Bauzeitung*, Vol. 65, Nos. 8 and 9, February 22nd and March 1st, 1947, pp. 98–102 and 107–112, 15 illustrations.)

HEATING installations for occupied rooms have always been required to maintain comfortable temperature conditions, generally in the order of about 18 deg. C. Also in theatres, etc., where many people congregate, the air has had to be maintained pure whilst the temperature is controlled to a reasonable level. Measurements of temperature are generally made at a position 15 m. above the floor in the centre of a room or, if the neighbouring rooms are heated, near the dividing walls.

The degree of air purity has usually been determined according to content of CO_2. However, unless this content is sufficient to be poisonous or detrimental to health, a more important contribution to a condition of discomfort would be the existence of other substances resulting from breathing and skin activity which are offensive and often obnoxious. A content of about 2·5 per cent CO_2 is necessary to be detrimental to health, and at 8 per cent it can be fatal, but these conditions are not being considered here. The theory that low CO_2 concentrations, below 2·5 per cent, and that "human poisons" are dangerously effective when inhaled is now considered obsolete. Experiments have shown that ventilation is a problem of temperature balance between the human body and the air surrounding it, but these do not discount the possibility that inhalation of smoke, dust, gases and vapours, etc., in the air can be dangerous.

HEAT AND WATER VAPOUR GIVEN OFF BY THE HUMAN BODY.

Rubner and Büttner have calculated that the heat given off by the human body is about 26 per cent by conduction and convection, 42 per cent by radiation, 3·6 per cent by exhalation of moisture, 26·4 per cent from the skin surface, and 2 per cent from the breath, apart from that conveyed by excrement. The results of other investigations differ slightly from these figures, however, and it is stated that nearly 50 per cent of energy dissipation is by radiation whilst about 50 per cent is partly conduction and more by transpiration. The heat given off by radiation, conduction and transpiration can be as much as 80 to 90 per cent, and perspiration can cause more heat to be exuded not only due to evaporation but because conductivity is increased by more than 100 per cent when the skin is wet. The proportion of heat dissipated by conduction and convection is larger when the air is cooler and more agitated, and the amount radiated is increased when the air is dryer.

The heat and water vapour given off by a human body depends on a number of factors, and Tables I, II, and III are of interest in this connection.

These tables of measurements are not influenced by variations due to taking food because they relate to persons subjected to investigation 12 hours after their last meal. It is known that the heat given off immediately after a meal can be greater by as much as 40 per cent.

Room temperature affects the way in which human heat is given off as well as the amount of water vapour and this can be noted by reference to Table IV giving figures from tests in the Research Institute of American Heating and Ventilating Engineers.

TABLE I.

Average discharge of heat and water vapour per hour of various persons. (Burger, Rietschels Leitfaden du Heiz-und Lüftungstechnik 9th edition 1930.)

	Heat given off, Cal/h.	Water vapour given off, g/h.
Baby	26	15
Child	52	20
Youth	90	40
Man, at rest ..	130	60
Man, working ..	200	130

TABLE II.

Total discharge of heat from the human body during various activities. (Benedict, Heat. and Vent., Vol. 31, 1934.)

Condition.	Heat given off, Cal/h.
Lying in bed	60
Sitting	63
Standing	66
Walking fast	180
Maximum bodily exertion ..	660

TABLE III

Total amount of heat given off by an adult during various activities. (Rybka, Klimatechnik, 1938, p. 27.)

Activity.	Cal/h.
Sitting still	96
Standing still	108
Walking, 3 km/h	190
" 5 km/h	262
" 6·5 km/h	347
" 8 km/h	632
Running slowly	571
Very strenuous exercises ..	641
Maximum exertion	833 to 1190
Tailor	120
Shoe maker	165
Carpenter	190 to 240
Metal worker	215
Builder	372

TABLE IV

Heat and water vapour given off by normally dressed man doing light sedentary work, in still air and at various room temperatures. (Berestneff).

Room temperature deg. C.	Heat given off by Conduction Transpiration Radiation (palpable or dry heat.)	Heat given off by Evaporation of water (damp heat)	Total Cal/h	Water vapour given off when the relative humidity of the air of the room is 30 to 70 per cent g/h
10	117	18	135	31
12	108	18	126	31
14	99	18	117	31
16	91	18	109	31
18	84	20	104	34
20	79	23	102	40
22	73	28	101	48
24	66	35	101	60
26	59	42	101	73
28	50	51	101	88
30	40	59	99	102

TABLE V

Basic data for air conditioning plants: Heat and water vapor given off by human beings. (See the Regulations for Ventilating Meeting Halls VDI Publishing Co. Ltd. Berlin, 1937.)

Indoor temperature deg. C.	20	21·5	22	25	27
Heat given off by conduction, convection and radiation, Cal/h	80	75	70	65	55
Heat given off by evaporation of water, Cal/h	20	25	30	35	45
Total heat given off, Cal/h ..	100	100	100	100	100
Water vapour given off, g/h	35	45	50	60	80

The figures in Table V are of the heat and water vapour given off by persons in various room temperatures. They are useful in planning for comfort by the installation of air conditioning plant, but it should be remembered that the persons tested were sitting still and that the total dry and damp heat given off, which is about 100k cal./hr. rises to 2 to 2·5 and sometimes to more than 5 times that amount if there is violent bodily exertion.

MEASURING EQUIPMENT AND DIAGRAMS FOR JUDGING THE CONDITION OF THE AIR.

For comfort the heat exchange ability of the human body should not be restricted, and the various ways in which it gives off heat should be understood and comprehended by formulæ and diagrams. In this connexion the following considerations are relevant :—

(*a*) *Temperature measurement.*

To measure temperature correctly care must be taken to position the thermometer so that it is not influenced by locally cold or hot conditions, such as near doors, windows, or heaters. The position should be carefully chosen and, as already mentioned, the reading should be taken at a height of about 1·5 m from the floor. Thermometers should be calibrated, protected against radiation, and contain the smallest amount of mercury necessary.

In winter the most comfortable temperature for a living room is 18 deg. C. except in houses with large windows allowing for a larger heat loss where it may be 20 deg. C. In other cases 12 deg. C. for workshops, where there is considerable manual effort, 12 to 14 deg. C. for bedrooms, 22 deg. C. for bathrooms, and 25 deg. C. for operating theatres, is sufficient. These figures are for radiator heating, however, and if the ceilings, walls, and floors are heated there will be less heat from the body by radiation, and the temperatures can be lower.

In summer when lighter clothes are worn, the temperature difference between outdoor and indoor conditions may necessitate a temperature rise indoors. Indoor temperature should rise with outdoor temperature when an air conditioning system is installed in central European conditions, but room temperatures should be higher in the Tropics.

The dry-bulb thermometer is not only useful for air temperature measurement, but it can also be used to measure radiated heat from the sun, warm walls, and fires, etc. For this two similar thermometers are used, one to reflect the heat rays and the other to absorb them. The radiation effect is shown by the difference indicated.

(*b*) *Measuring Temperature and Humidity.*

Outdoor and indoor "climates" can be more reliably judged by measuring the relative humidity of the atmosphere as well as the temperature. Hygrometers and psychrometers (wet and dry-bulb thermometers) may be used for this and the conditions can be checked by reference to the psychrometric table.

The limits of relative humidity which, for comfort, should not be greatly exceeded are indicated by the broken line curves in Fig. 1. These, however, are only approximate indications and, within the range of comfort, whether the degree of humidity should be nearer the upper or the lower limit depends on various conditions, such as the nature of employment. A condition approaching that indicated at the upper limit (*a*) may be pleasant for sedentary workers, but for strenuous work the low limit (*b*) may be best, particularly in high temperatures, if excessive perspiration is to be avoided. From a hygienic point of view relative humidity should be as follows, when the air is moving and heavy work is being done :—

15 to 18 deg. C.	up to 70	per cent
18 to 20 deg. C.	about 60	„
21 to 23 deg. C.	„ 50	„
24 deg. C.	„ 40	„

It should be less for very heavy work. The humidity in meeting rooms in winter, at a room temperature of 20 deg. C. should not be less than 35 or more than 70 per cent. In summer at room temperatures up to 22 deg. C. the relative humidity should not be more than 70 per cent, or 60 per cent with a higher temperature. The summer range from 17 to 24 deg. C. is shown enclosed by a frame in Fig. 1 and within this frame the

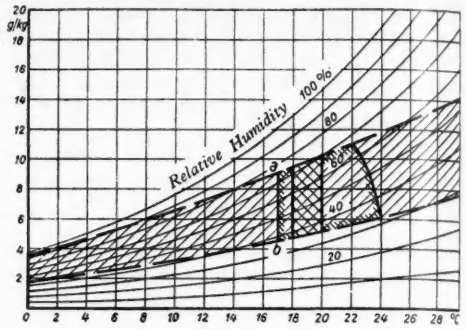


Fig. 1. **Absolute humidity in gr per kg of dry air at various temperatures and relative humidities of the air.** Broken lines: upper and lower limits of comfort indoors and out when the air is practically still.

section relating to the heating period between temperatures from 18 to 20 deg. C. is cross-hatched. The right-hand frame line runs from 24 deg. C. on the lower limit curve to 22 deg. C. on the upper limit curve, because, for maximum comfort, the relative humidity should be near the low limit when the temperature increases from 22 to 24 deg. C.

(*c*) *Consideration of temperature, humidity and air movement (effective temperature.)*

More heat is dissipated by increased convection or forced air movement, and the faster the air moves past the body the higher the air temperature should be. Investigations nearly 25 years ago by the American Society of Heating and Ventilating Engineers introduced the expression "effective temperature" in connection with the "comfort zone." It is understood to refer to the temperature of still air saturated 100 per cent (or 50 per cent according to later statements by Crowden and Bedford), which will give out a feeling of warmth equal to that of the air which is to be judged for comfort.

Anemometers are used for measuring air speeds and some types can measure speeds as low as 0·25 m/sec. with sufficient accuracy. For lower air movements in rooms, etc., hot wire equipment or, preferably, the Katathermometer is suitable for measuring air speeds even less than 0·1 m/sec.

The lower container of this thermometer, which is filled with colored alcohol, is immersed in water at 45 to 60 deg. C. for a short time, and then dried before being suspended where the air condition is to be determined. The time taken by the alcohol to fall from the 38 deg. C. to the 35 deg. C. mark is read from a stopwatch, and the heat given off in milli-calories per cm^2 of the surface is divided by the cooling time and gives the Kata value. Simultaneously the temperature at the position of the thermometer should be measured and the air-speed can then be obtained from the Kata-diagram, Fig. 2.

The empirical formulæ given by L. Hill for determining the Katavalue A, are :

$$A = (0{\cdot}20 + 0{\cdot}40\sqrt{W}) \,.\, (36{\cdot}5 - t_l), \text{ for } w \leq 1$$

$$A = (0{\cdot}13 + 0{\cdot}47\sqrt{W}) \,.\, (36{\cdot}5 - t_l), \text{ for } w \geq 1.$$

when w = air-speed in m/sec.

and t_l = air temperature in deg. C.

Air speeds in rooms should be less and not constitute uncomfortable draught. With thick walls and normal windows air-speeds in summer, when the temperature difference from outdoors to indoors is small, are generally less than 0·1 m/sec., but when air movement is caused by opening and shutting doors, and ventilators, etc., it will be between 1 to 2·5 m/sec. Measurements have shown that in artificially ventilated

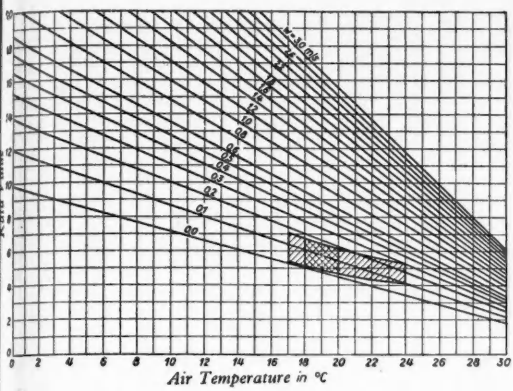


Fig. 2. **Kata diagram.**

rooms air speed should not be more than 0·2 or 0·25 m/sec. except when the temperature is high as for example in crowded cinemas. The temperature of entering air should be higher, or not much lower than room temperature. Outdoors an air speed of 0·5 m/sec. is considered calm but indoors i is too high and speeds of 0·3 m/sec. are very near the permissible limit. If the entering air is cooler than the air in a room, anemostats, etc., should be used to control strong air currents. In living rooms the speed should not even be more than 0·1 to 0·15 m/sec. These low air speeds influence the heat discharge of the body favourably and remove the stagnant air, which surrounds the body as its " atmosphere proper."

TABLE VI

Range of comfort in living rooms the wall temperatures of which do not differ greatly from the temperature of the air.

Room temperature deg. C.	Limits of Relative humidity per cent	Limits of Air speed m/s
17	37–75	0·01–0·16
18	36–73	0·01–0·17
19	35–71	0·01–0·18
20	35–70	0·02–0·19
21	34–68	0·03–0·21
22	33–67	0·04–0·23
23	33–65	0·07–0·26
24	32	0·10–0·30

Table VI was compiled and Fig. 3 was made with respect to conditions of comfort plotted in Fig. 1 and to the permissible air speeds plotted in Fig. 2.

Assuming that higher air speeds should correspond to greater humidity our adjustment of air speed can be adapted to suit room temperature to obtain the best condition of comfort.

As a guide to reading Fig. 3, the following examples can be considered :—If a room temperature is 19 deg. C., and humidity is between 35 and 71 per cent, the air speed should be between 0·01 and 0·18 m/sec. The best conditions, however, would be at 50 per cent humidity and an air speed of 0·08 m/sec. If the temperature is 20 deg. C. and the relative humidity is 60 per cent then the best condition is obtained with an air speed of 0·14 m/sec. In winter time with indoor temperatures at about 18 to 20 deg. C. the relative humidity within the given limits is not so significant relative to warmth and comfort, although higher temperatures with humidity, or considerable humidity with extreme cold, and gusty air, are unpleasant conditions.

Fig. 3 is particularly useful to indicate the interrelationship between temperature, humidity and air speed. To facilitate this an equipment can be used for taking the necessary readings. This equipment weighs

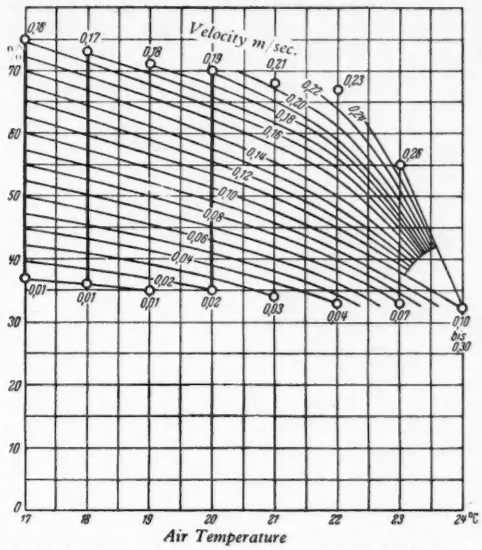


Fig. 3. **Comfort diagram for sedentary occupations, the clothing being adapted to the temperature. Wall temperature differs very little from the room temperature. (Hottinger.)**

about 4½ lbs. and consists of a tripod supporting a cross arm, from which a hygrometer, thermometer, and Katathermometer can be suspended, a full thermos flask, a stop-watch, note book, and means for packing and easy transport.

The best-known psychrometer for most accurately determining humidity is the Assmann, but the Hænni aspiration psychrometer or the Krüger, St. Gallen, centrifugal psychrometer are often used. After taking readings from both the dry and wet bulb thermometers the relative humidity is obtained by Sprung's formula :

$$\varphi = \frac{100}{p_r}\left[p_f - \frac{b}{1510}(t_r - t_f)\right] \text{ per cent}$$

in which

φ = the relative humidity of the air

t_r and t_f = dry-bulb and wet-bulb temperatures in deg. C.

p_r and p_f = the saturation pressure of the water vapour at the temperatures t_r and t_f in mm. of mercury

b = barometric height in mm. of mercury

The psychrometric charts worked out from this formula, such as Fig. 4 which are generally used relate to a barometer height b of 755 mm. of mercury at sea level. Thus for a dry-bulb temperature of $t_r = 20$ deg. C. and a wet-bulb temperature of $t_f = 15$ deg. C. the relative humidity is $\varphi = 59$ per cent. For heights above sea-level the values must be corrected.

The effective temperature when the air is still, or moving less than 0·15 m/sec., can also be read from Fig. 4, or from a chart made from particular psychrometric measurements. In the above example $t_{eff} = 18{\cdot}3$ deg. C. which means that air at 20 deg. C. saturated 59 per cent gives the same feeling of warmth as air at 18·3 deg. C. saturated 100 per cent. Also an effective temperature of $t_{eff} = 19$ deg. C. corresponds to air at 20·3, 21·2 and 22·3 deg. C. saturated 70, 50, and 30 per cent respectively.

Mass experiments were carried out in America to determine effective temperatures. A number of persons moved from one room to another, and the temperatures and humidities were varied until at least 50 per cent felt the heat to be the same after the change. The American summer and winter comfort zones are

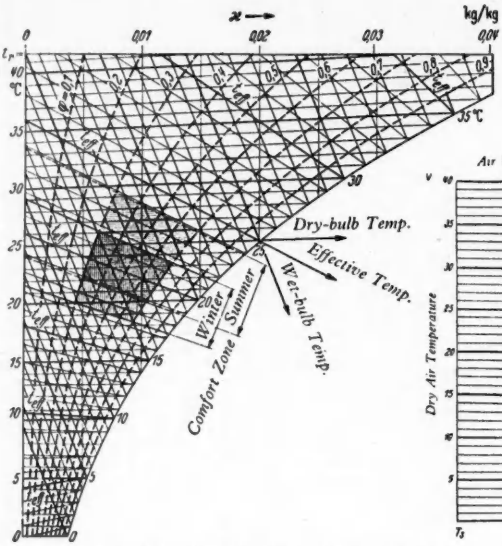


Fig. 4. **Psychrometric chart for determining the effective temperature from the dry-bulb or wet-bulb temperature when at rest, or engaged in light activity and wearing street clothing in still air.**

indicated by cross-hatching in Fig. 4. They do not correspond with the optimum comfort zone in central Europe because of the differences of climate race, habits, and clothing.

In Table VII the figures relate to comfortable air conditioning in rooms occupied in summer time for less than three hours at a time. Table VII also shows that when there is air movement the effective temperature is reduced. This influence is shown in Fig. 5.

Temperatures established by wet and dry-bulb thermometers are plotted, and joined by a line which intersects the air speed curve at a point indicating the effective temperature.

The effective temperatures for air speeds of 0 m/sec. given in Table VII correspond to those determined

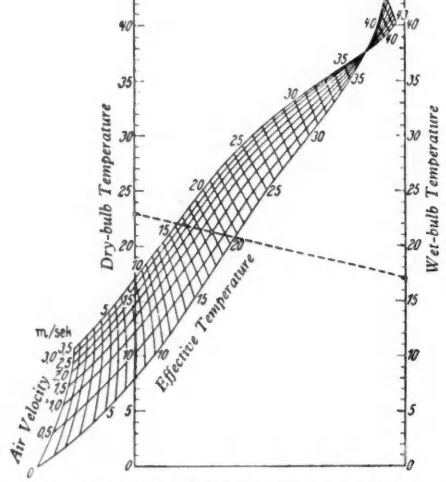


Fig. 5. **Table to determine the effective temperature (source as for Fig. 4).**

from Fig. 4 because these related to still air.

For Fig. 5 the body is considered to be at rest, and that outdoor clothing is worn. For other conditions the diagram would be different.

For example:—According to Fig. 5 a dry-bulb temperature $t_r = 23$ deg. C. and a wet-bulb temperature $t_r = 17$ deg. C., corresponds to a relative humidity $\varphi = 54$ per cent and effective temperature, at rest, $t_{eff} = 20{\cdot}8$ deg. C. Fig. 5 shows a similar result for an air speed of 0·0 m/sec. and that, for air speeds of 0·5, 1·0, 2·0, and 3·0 m/sec., the effective temperature drops to 20, 19, 17·5 and 16·5 deg. C. respectively. If the top part of the body is bared the effective temperatures will be lower.

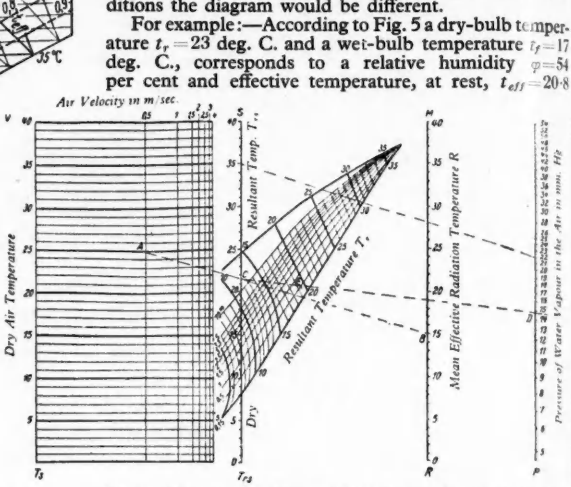

Air Velocity in m/sec.
Dry Air Temperature
Resultant Temp. T_r
Resultant Temperature T_r
Dry
Mean Effective Radiation Temperature R
Pressure of Water Vapour in the Air in mm. Hg

Fig. 6. **Diagram for determining the resultant temperature for persons in ordinary clothing engaged in very light activity. (A. Missenard.)**

TABLE VIII

Dry-bulb, wet-bulb and effective room temperatures for various external temperatures (Summer conditions ; for periods of less than 3 hours). (Rybke, Klimatechnik,1938, p.31). A. Missenard.

Dry-bulb temperature out of doors deg. C.	Approx. conditions of the air in the room.		
	Dry-bulb temperature deg. C.	Wet-bulb temperature deg. C.	Effective temperature deg. C.
35	26·5	18·3	22·5
32	25·5	18·0	22·0
29·5	24·7	17·8	21·5
27	24·0	17·5	21·0
24	23·0	17·2	20·5
21	22·0	17·0	20·0

Fig. 5 further shows that the normal body temperature which approximately corresponds to an effective temperature of about 35 to 38 deg. C. is no longer affected by air speed, and that at higher temperatures the body absorbs heat from its surroundings. Such conditions, however, cause an accumulation of heat which can only be endured for a short time before affecting health and even causing death.

Fully saturated air, however, makes the discharge of heat from the body difficult and cannot therefore be considered as a condition for comfort.

(*d*) *Consideration of temperature, humidity, and air speed, and of the mean radiation temperature of walls (resultant temperature).*

For a satisfactory assessment of indoor conditions the mean radiation temperature of walls should be considered in cases when wall temperature differs greatly from the average air temperature. For example, in assembly halls, used infrequently, the walls may be cold and therefore the air temperature should be raised above that necessary if they were warm, although not too much if the ceilings are heated. Obviously if the air and wall temperatures are the same the effective and resultant temperatures will be the same also.

The radiation temperature of a building depends on the structure of its outer walls and the number and size of the windows and whether they are single or double. The type of heating is also a factor. In rooms with ceiling heating the temperature of the air is lower than the ceiling, walls and floor, but it is higher with heating by radiators. In both cases, however, it is lower at the windows and outside walls. This temperature distribution can be explained easily: When the ceiling is heated radiation heats the walls and the floor without large absorption losses, and the air is heated by conduction and convection, therefrom. With radiator heating the heated air gives heat to the walls because they are cooler.

Ceiling heating and demands on the grounds of hygiene led to the development in air conditioning which required a scale taking the average radiation of the walls into consideration as well as temperature, humidity and air speed. This scale allows for the assessment of comfort conditions in workshops, where much heat is developed, as well as in theatres, etc.

If readings with wet and dry-bulb thermometers have been taken, the Katathermometer has been used, and the mean effective radiation temperature of the walls have been measured by using a Vernon Globe thermometer, Fig. 9, or a Missenard dry resultant thermometer, Fig. 10, then Figs. 6, 7 and 8, can be used to determine resultant temperatures taking occupation and clothing into account. The Vernon Globe thermometer has a bulb 15·2 cm. dia. and takes air temperature, wall temperature, and time into consideration, whilst the Missenard dry resultant thermometer includes humidity and has a bulb diameter of 9 to 10 cm. The bulbs are blackened copper hollow spheres into which mercury thermometers are inserted and, according to Missenard the diameter for the resultant thermometer should be chosen so that the ratio of heat radiated and that given off by convection is about 1·1. The bulb should be only 6 cm. dia. to suit conditions for a person taking bodily exercise, because it will thus be less sensitive to radiation. Also for resultant thermometers the copper bulb has strips arranged crosswise which are 1·3 cm. wide and draw up moisture from the container on which the bulb is mounted when humidity is to be taken into account. These strips cover 36 per cent of the surface of the bulb.

In Fig. 6 the following determination of resultant temperature is shown by broken lines.

Dry air temperature (Scale T_s) $t_r = 25$ deg. C. } Point
Air speed (Scale V) $v = 0{\cdot}5$ m/sec. } A

The mean radiation temperature determined by the Vernon ball thermometer (Scale R) = 15 deg. C. (Point B).

The point at which a straight line from A to B intersects the scale for the resulting temperature $T_{rs} = 21{\cdot}5$ deg. C. (Point C).

The pressure of water vapour in the air is determined in mm. of mercury from the psychrometric measurement. Point D on scale P is joined to point C by a straight line which intersects the resultant temperature field at point E, where the air speed of 0·5 m/sec. is indicated, and the resultant temperature reading is 19·5 deg. C. Thus the air considered gives off heat equal to that of still air at 19·5 deg. C., and 100 per cent saturation.

Using the same assumptions and according to Fig. 7 the resultant temperature for a human being without clothes is 20·5 deg. C., and from Fig. 8 it is 18 deg. C. for a normally clad person engaged in manual labour. It is apparent from Figs. 6, 7, and 8 that for the example above the pressure of water vapour in the air is 15 mm. of mercury, and at 25 deg. C. and 100 per cent saturation it is 23·75 mm. of mercury. Thus the relative humidity of the air is

$$\frac{15 \times 100}{23{\cdot}76} = 63 \text{ per cent.}$$

This corresponds to a temperature of the wet-bulb thermometer of about 20 deg. C. The effective temperature established without reference to wall temperature is 22 deg. C. It is clear from the difference between the effective temperature and the resultant temperature, 2·5 deg. C. that, if there is much heat radiation, the resultant temperature must be relied upon as a standard for obtaining satisfactory results. Use of the dry resultant thermometer more easily determines the dry resultant temperature (point C) which can be read off directly. The left-hand side of the diagram and scale R are not necessary and only lines corresponding to C—D are needed to find points corresponding to E.

Dufton (Garston, England), and Bedford (London), refer to equivalent temperature, and equivalent heat, respectively and mean the same as resultant temperature referred to by Missenard. An improved Eupatheoscope invented by Dufton for taking this measurement consists of an electrically heated blackened cylinder 55·8 cm. high and 19 cm. dia. which allows for measuring the influence of the air temperature, the radiation of walls, and air movement. The energy feed is regulated

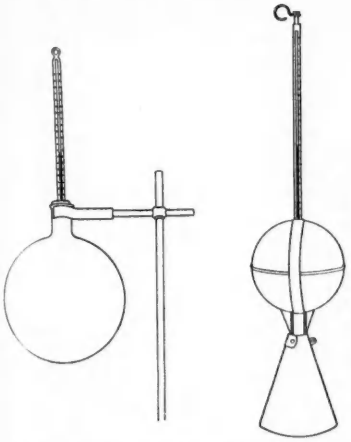


Fig. 9 (left). **Vernon ball or globe thermometer.**
Fig. 10 (right). **Missenard's resultant thermometer.**

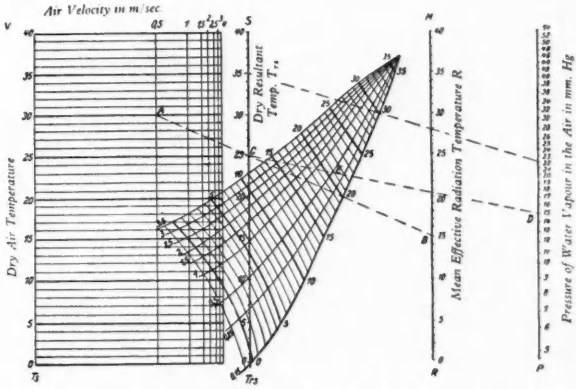

Air Velocity in m/sec.
Dry Air Temperature
Dry Resultant Temp. T_{rs}
Mean Effective Radiation Temperature R
Pressure of Water Vapour in the Air in mm. Hg

Fig. 7. **Diagram for determining the resultant temperature for unclothed human beings at rest. (A. Missenard.)**

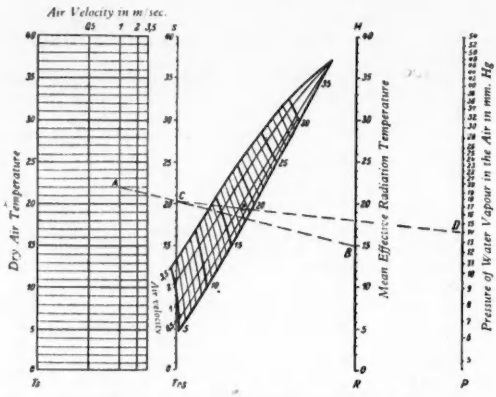

Air Velocity in m/sec.
Dry Air Temperature
Mean Effective Radiation Temperature
Pressure of Water Vapour in the Air in mm. Hg

Fig. 8. **Diagram for determining the resultant temperature for human beings in ordinary clothing doing bodily work. (A. Missenard.)**

so that the surface temperature is adapted to that of the human body and remains constant. A branch circuit heats a thermometer which is contained inside with a scale on the outside of the cylinder. The ratio between the heating and branch currents remains constant so that, when calibrated, the equivalent heat can be read directly from the thermometer.

The Thermo-Integrator used by Winslow and Greenburg (U.S.A.) for the same purpose is another apparatus which does not include the effect of air humidity. There is a requirement for an inexpensive equipment which would measure all influences simultaneously and give a direct reading of the resultant temperature. In the meantime the influences must be measured in the best way possible and the results evaluated with the help of diagrams. When the wall temperatures of rooms are not abnormally high or low it is sufficient to measure temperature only although, in special cases, the humidity and air speeds should be known also. Results can be judged from Figs. 3 or 5.

The determination of the resultant temperature is necessary in rooms with ceiling-, wall- and floor-heating, sometimes in workshops with hot stove walls and in rooms with large windows, very cold walls or similar cooling surfaces. This resultant temperature is not easy to measure, however, as has been explained before, and one must have the necessary knowledge and proper instruments for this kind of measurement, which has therefore only been applicable to research work.

In a report on the International Conference in June 1937 on Regulating the Climate in Buildings ter Linden (Delft) wrote :—" All these equipments measure the average radiation at a certain position in the room. This is quite allowable if the temperatures do not differ very much. If there are great differences, the intensity of the radiations in various directions should also be measured. An equipment placed between a cold window and a hot radiator would give a good mean value, whereas a person would hardly feel comfortable in that position. Since the above-mentioned equipments cannot measure radiations in different directions, the speaker would like to draw attention to the cube used at Delft which can measure radiation at each of its six surfaces."

Formulæ as well as diagrams can be used to determine comfort conditions. Those determined with the aid of the comfort scales of Bedford (London) and V. Zuilen (Holland) are :—

$$S = P - 0{\cdot}1 \times t_l - 0{\cdot}0968 \times t_w - 0{\cdot}0372 \times p + 0{\cdot}0367 \times \sqrt{c} \times (37{\cdot}8 - t_l)$$

where $P = 7{\cdot}83$ in winter and $8{\cdot}45$ in summer.
t_l = air temperature in deg. C. 0·5 m. above the floor.
t_w = wall temperature in deg. C.
p = pressure of the water vapour contained in the air in mm. of mercury.
c = air speed in m/sec.

$S = 1$ much too warm	$S = 5$ comfortably cool
$S = 2$ too warm	$S = 6$ too cool
$S = 3$ comfortably warm	$S = 7$ much too cold.
$S = 4$ comfortable	

As an example take Fig. 3 :—

$t_l = 19$ deg. C., $t_w = 18$ deg. C., $c = 0{\cdot}08$ m/sec., and the relative humidity is 50 per cent. The vapour pressure $p = 15{\cdot}48 \times 0{\cdot}5 = 7{\cdot}74$ mm. of mercury.

In winter $S_w = 7{\cdot}83 - 0{\cdot}1 \times 19 - 0{\cdot}0968 \times 18 - 0{\cdot}0372 \times 7{\cdot}74 + 0{\cdot}0367 \times \sqrt{0{\cdot}08} \times (37{\cdot}8 - 19) = 4{\cdot}1$.

According to V. Zuilen tests in living rooms and lecture halls showed that use of the formulæ is practicable. Instead of making this type of calculation, however, a monogram could be used.

Bedford's equation for measuring " equivalent temperature " t_l' relates to still air and equal wall and air temperatures. It is much used in England as follows :—

$t_l' = 0{\cdot}522 \times t_l + 0{\cdot}478 \times t_w - 0{\cdot}205 \times \sqrt{c} \times (37{\cdot}8 - t_l)$ deg. C.

taking the same values as in the preceding case :—

$t_l' = 0{\cdot}522 \times 19 + 0{\cdot}478 \times 18 - 0{\cdot}205 \times \sqrt{0{\cdot}08} \times (37{\cdot}8 - 19) = 17{\cdot}4$ deg. C.

The humidity is not considered and Dufton's Eupatheoscope is used for taking the measurements.

THE PURITY OF THE AIR AS A STANDARD OF COMFORT.

The above examples deal with the relationships of heat given off by the body, but air purity is also a factor for comfort. Odiferous and unpleasant substances given off by the body have been mentioned, and to these such other impurities as tobacco smoke and smelly vapours from other causes may be added. Ventilating or air-conditioning plants should be adjusted to eliminate such impurities by changing the air. The rate of air change will depend on the type of room and Table VIII is useful in this connection. The important

TABLE VIII

The amount of fresh air required in installing ventilating or air conditioning plants. (M. Hottinger—Lüftungs v. Klimaanlagen. Verlag J. Springer Publishing Co. Berlin, 1940. Table II, p.57).

	Per Head m³/h	Multiple of cubic contents of the rooms.
Rooms in which the air is polluted by heavy smoking, etc. Halls, theatres, cinemas, meeting rooms, cafés, refreshment rooms, etc. ..	20–30	3–5
Rooms in which heavy smoking takes place: restaurants, conference rooms, theatres, etc., where smoking is allowed	30–50	5–10
Booking offices, vestibules of banks, travel bureaus, etc.		2–3
Sick Rooms	20–30	2
Operating theatres		3–5
Schoolrooms for children up to 12 years of age	15	2
Schoolrooms for children over 12, lecture halls, auditoria, etc.	20	3
Offices and rooms in factories which are fully occupied but where the air is not specially impure	20–30	3–5

considerations is that the amount of air per person is kept above the minimum necessary for the room capacity, and if the ceiling is low maximum air allowances should be provided for.

Wear Tests of Plastics

By N. N. SAWIN. (From *Maschinenbau und Wärmewirtschaft*, Vol. 1, No. 5/6, November/December, 1946, pp. 103-108, 7 illustrations.)

ACCOUNT is given in this article of numerous wear tests of different kinds of plastics. They concern synthetic materials used in the manufacture of bearings, bushings, gears, rails, etc., in automobiles, aeroplanes, electrical equipment, and machine tools, as well as in the production of general engineering parts and household appliances.

Plastics are light weight materials of sufficient strength and good machinability. A low modulus of elasticity hampers their application in fits with a very small tolerance.

	Laminated Materials.	Bearing Bronze.	Steel.
Modulus of Elasticity, pounds per square inch ..	1,000,000—1,420,000	16,000,000	30,000,000

In plastic bearings there is danger of overheating because of their low heat conductivity. This often requires the application of a special coolant at temperatures above 212 deg. F (for instance in bearings of rapidly rotating shafts.)

Publications on plastics, investigation of their physical and mechanical properties, and the description of their practical application were numerous before and during the war, but among the large number of research reports, those on wear were entirely lacking. However, knowledge of numerical values of the wear of plastics in relation to similar work with metallic or other materials is very important for the designer as well as for the customer.

MATERIALS TESTED.

(1) Synthetic resins in which phenol and formaldehyde are the principal basic materials.

(2) Laminated materials, with 50 per cent resin, consisting of a number of cloth layers pressed between heated plates at 2500-2800 lbs. per sq. in.

(3) Plywoods with a resin content of 15-30 per cent composed of a number of thin sheets of wood put one upon another under a pressure of 1500-7500 lbs. per sq. in. The pressure is applied in open or closed moulds.

(4) Scraps of plywood (0·15 sq. in.) 0·004 to 0·020 in. thick used as a filler, saturated with a water solution of Phenol-Cresol resin and pressed into moulds to obtain finished or semi-finished parts.

In order to facilitate fastening them in the testing machine, test pieces, $2 \times 1^{3}/_{16} \times {}^{13}/_{32}$ and $4 \times {}^{51}/_{64} \times {}^{13}/_{32}$ inches in size were cut from large plates.

TEST PROCEDURE.

The wear tests reported herein were performed on the Skoda-Sawin* testing machine, the principle of which is shown in Fig. 1. The tool is a standardised tungsten-titanium carbide wheel $1^{3}/_{16}$ in. in diameter and 0·100 in. thick. This wheel of sintered carbide is unaffected by wear when testing plastics.

The load on the wheel can be varied within limits of 0 to 55 lbs. With the aid of pulleys and a gear box it is possible to obtain different circumferential speeds of the wheel from 0·4 to 8 ft./sec. During the test, the work in the shape of a prism, as well as the wheel are cooled to room temperature by a heavy flow of coolant composed of a $^{1}/_{2}$ per cent solution of potassium chromate (K_2 Cr O_4). After a certain number of revolutions of the wheel, the machine is stopped and the microscope is swung over the impression formed in the test bar. By means of moving threads in the microscope, the length of the impression is measured and the volume thereof is determined from tables in $^{1}/_{1000}$ cubic millimetres. The accuracy of results obtained on the machine is equal to $\pm$ 6 per cent.

*Prof. N. Sawin, "The Effect of Surface Stress on the Wear of Metals," *Machinery* (London), Vol. 50, May 6, 1937.

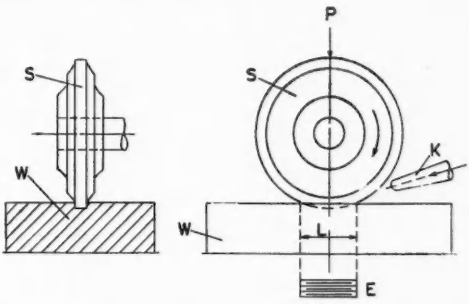


Fig. 1. **Principle of the Skoda-Sawin machine:** S, wheel; W, testbar; K, coolant nozzle; F, wearmark; P, load on wheel.

The changes in the grinding ability of the sintered tungsten carbide wheel in relation to the type of material tested, are generally not of essential importance. The principal factor is the work of the small wear particles between the wheel and the test bar. The sintered carbide wheel serves only as a solid unchangeable support for these particles. A sufficient impression in the tested material can usually be formed with 3000 revolutions of the sintered carbide wheel. The work of the wear particles among themselves and on the test bar acquire a constant character. Thus the numerical values obtained characterise the wear of the tested material by its own wear particles in powder form.

The analysis of wear phenomena when testing different materials with the carbide wheel, clears up the important role which the wear particles play and represents an interesting aspect of the theory and practice of wear of finished machined parts.

In repeated tests the degree of scattering of wear test values depends, primarily, on the homogeneity of the structure of the materials tested. The combination of test conditions (circumferential speed, load and the number of revolutions of the wheel) may also influence the degree of scattering.

A great number of tests of synthetic materials established that a load of 11 lbs. (5 kg), circumferential speed of 3·281 feet per second (1 metre per second), and an average of 3000 revolutions for the carbide wheel are the most advantageous conditions for testing all kinds of these materials.

TYPICAL TEST RESULTS.

Thermoplastic resin in the untempered state appears as a material with a very uneven structure and great internal stresses, therefore the values of wear vary from — 80 per cent to + 150 per cent from the average value. The non-homogeneity of the structure and great internal stresses are distinctly seen in polarized light. However, after 6 hours of tempering at 212 deg. F. the structure becomes more even and the stresses apparently disappear. Material which has been tempered for 24 hours is quite uniform ; the wear decreases and is constant.

With an increase of load on the wheel, or with an increase in the number of revolutions of the wheel,

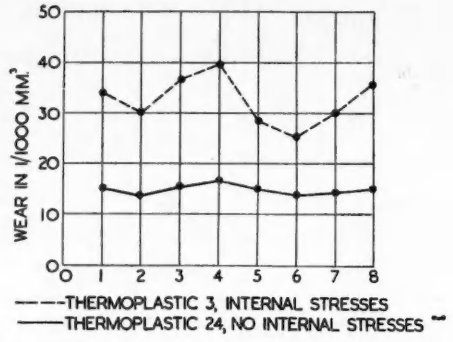


Fig. 2. **Values of wear in different locations on the test bar.**

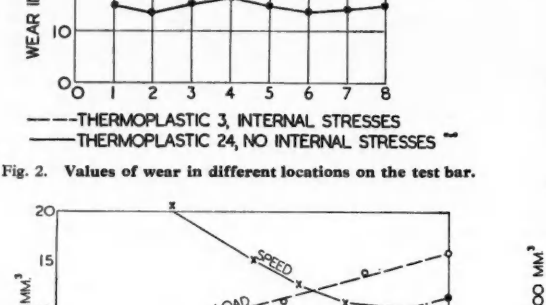
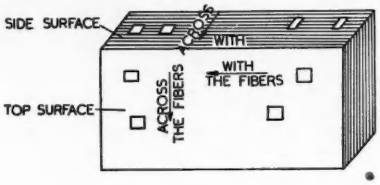


Fig. 3. **Wear of a thermoplastic material tempered for 24 hours, in relation to speed, load and number of revolutions.**



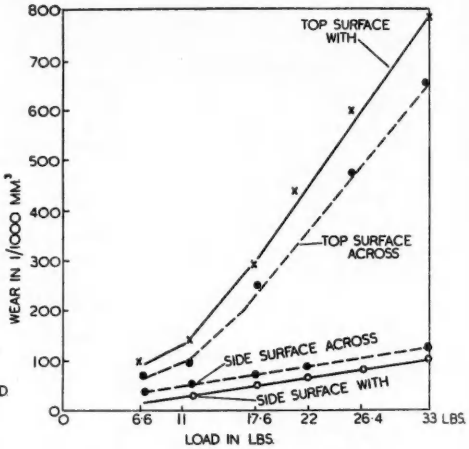


Fig. 4. **Laminated coarse cloth plastic.**
Effect of the load on wear at a speed of 3·281 feet per sec.

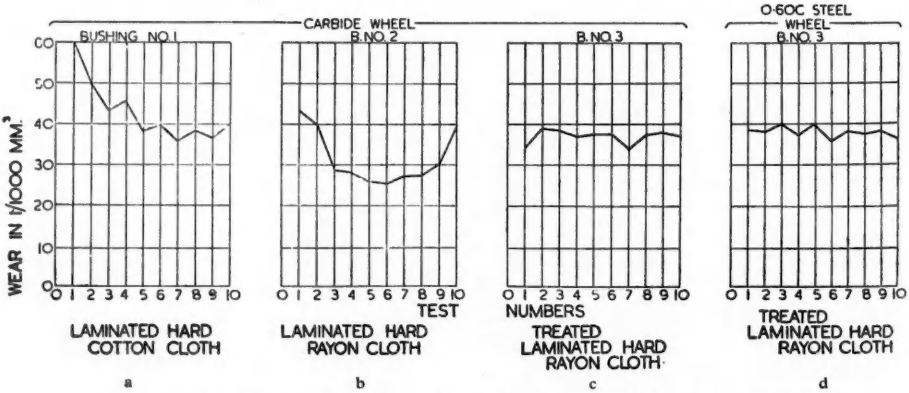


Fig. 5. **Values of wear of three bushings of laminated fine cloth plastic No. 1, 2 and 3.**
Tested with sintered tungsten carbide wheel and 0·60 C. steel wheel at 11 lbs., 3·281 feet per sec., 3000 r.p.m. along the fibre on the top surface.

wear increases linearly. A great number of tests have shown that all synthetic materials follow the same law in respect to speed and load on the wheel.

Fig. 2 is a diagram indicating wear of Dekorit (a thermoplastic resin) under normal conditions of testing with the carbide wheel, after 3 and 24 hours, respectively, of tempering. The relation of wear of Dekorit after 24 hours of tempering to the number of revolutions, load and speed is shown in Fig. 3. With an increase in speed of the wheel from 0·82 to 6·56 ft. per sec. the wear decreases and attains its minimum values at a speed of 3·28 to 6·56 ft. per sec.

In synthetic materials made with layers of cloth it is necessary to distinguish the resistance to wear in the top surface and at the side along the fibres and across them. The test of coarse laminated cloth material, see Fig. 4, has shown that its resistance to wear is 10 times better on the side than on the top surface.

In Fig. 5 a—d are shown the test results of three types of bushings of laminated material. Bushing No. 3, a specially prepared rayon, highly homogeneous and resistant to wear, was tested with the carbide wheel as well as with a wheel of ordinary 0·60 per cent carbon steel. The values of wear are nearly the same. Bushing No. 1 appears to be weaker. It was interesting to note that when the same bushings were tested for several days on a special bearing test machine and also in the shop for several weeks, the same results were obtained as in a laboratory test of only a few hours' duration.

The wear resistance of laminated wood consisting of layers of plywood, is approximately twice as much on the top surface as on the side surface. The resistance to wear of the so-called "woodscrap materials," made of small pieces of plywood, is the same on both the top and side surfaces. The scattering of individual values is less on the side surface. Therefore, the wear values on this side of the material may be considered as constant. Investigation of different kinds of laminated wood in regard to the condition of their manufacture,

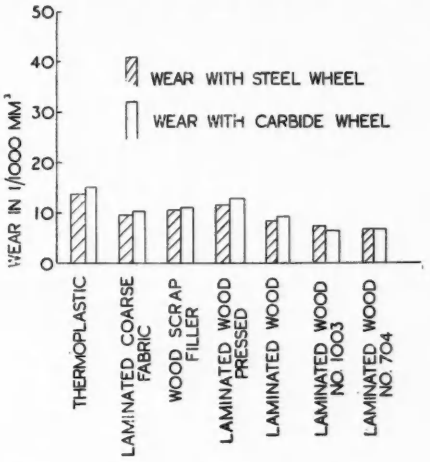


Fig. 6. Comparison of wear values of 7 synthetic materials. Tested with two wheels, sintered tungsten carbide and steel, on the side surface at 11 lbs., 3·281 feet per sec. and 3000 r.p.m.

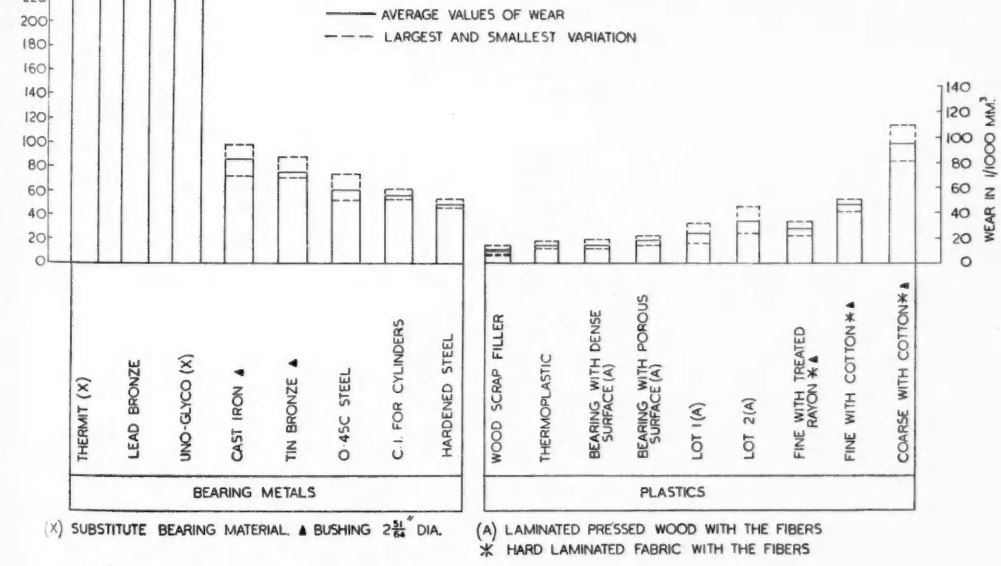


Fig. 7. Wear values in 1/1000 cubic millimetres of synthetic materials and alloys used in bearings. Tested on Skoda-Sawin machine. Test conditions 11 lbs., 3·281 feet per sec. 3000 r.p.m. of the carbide wheel, cooled with a ½ per cent solution of potassium chromate to about 68 deg. F.

confirmed the fact that minimum wear occurs on the top surface of samples with a resin content from 15 to 20 per cent made under a pressure of 1400 to 2100 lbs. per sq. in.

All samples pressed at a temperature of 320 deg. F. and a load of 4250 lbs. per sq. in. showed minimum wear regardless of the resin content.

Now, the question arises, whether the values of wear obtained with the carbide wheel have a practical significance for the synthetic materials. Is it possible to rely upon these values in day-to-day manufacturing operations when the synthetic materials are working in combination with materials of a hardness considerably less than that of carbide ? E.g., shafts of soft steel in bushings of synthetic materials ?

A series of parallel tests was carried out to answer this question. Instead of a carbide wheel a wheel of a steel such as is used for shafts was employed. The graph, Fig. 6, shows the comparative test results of seven kinds of synthetic materials when using a carbide wheel and one of steel. It is clear that the values of wear for both wheels are approximately the same. Therefore, the carbide wheel can be considered as a reliable practical instrument for the wear determination of synthetic materials.

In Fig. 7 are plotted the results of wear tests with bearing metals and plastic materials. The excellent wear properties of plastics show up.

CONCLUSIONS.

The tests have shown that the powdered wear particles of the test bar act as the principal factor in the formation of the impression. The carbide, while itself contributing very little, is a base or carrier for the wear particles. Thus the wear values obtained characterize the wear of a synthetic material by its own wear particles. The same phenomenon is observed when the carbide wheel is replaced by a steel wheel. In practical applications, e.g., the work of a steel shaft in bearings of synthetic materials, the type of mechanical wear is of the same character as in a laboratory test. However, actual wear in the shop is much less : (1), because of a considerably lower unit pressure than during laboratory tests ; and (2), because of lubrication, since in laboratory tests only a coolant is used.

The tests show that (a) with increasing speed of the wheel up to 5 feet per second (1·5 metres per second) the wear of synthetic materials decreases, reaching its minimum value at that speed and (b) wear increases in direct proportion to increase of load on the wheel and to increase in number of revolutions. The same tests showed the most advantageous wear test conditions of synthetic materials with the sintered carbide wheel to be 11 lbs. (5 kg.), 3·281 feet per second (1 metre per second) and 3000 revolutions of the wheel. This will give the designer a choice to obtain practical and reliable results. In such a case the speed is near the practical speed used in transmissions but the actual pressure of the bearings is exceeded many times. This choice can be made because of the linear relationship between wear and load and is advantageous in finding the values for wear in a relatively short period of time. It is obvious that for the practical application of the test results, the laboratory test set-up for synthetic materials may be similar to shop conditions, but the tests would require excessive time.

GERMANY

The Strength and Structure of Compression and Transfer Mouldings

By W. WEIGEL. (From *Kunststoffe*, Vol. 37, No. 1, January, 1947, pp. 11-13, 12 illustrations.)

ELECTRICAL insulators transfer moulded from phenolic powders with cellulose and fabric fillers have shown concentric cracks around the transfer gate, and mouldings have had to be scrapped. Also the mechanical properties of transfer moulded specimens were inferior. The specimens were of cylindrical shape, approximately 3 in. diameter by 3 in. high, having a moulded thread on the plain surfaces, and the transfer gate was located at the centre of the cylindrical surface. Compression moulded specimens gave satisfactory results, and experiments were therefore carried out to investigate the transfer moulding method with respect to mechanical strength.

Standard test bars of 120 × 15 × 10 mm. size were transfer moulded using the following powders :—

Phenolic resin with wood flour filler, type 31.
Phenolic resin with cellulose fibre filler, type 51.
Phenolic resin with fabric filler, type 71.
Phenolic resin with cellulose fibre filler, type 54.
Phenolic resin with fabric fibre filler, type 74.

Types 54 and 74 are of improved notched bar impact strength, i.e., medium shock resisting types.

The test bars were transfer moulded in three ways :—

Bar S_1 : transfer gate in the middle of the 120 × 10 mm. side.

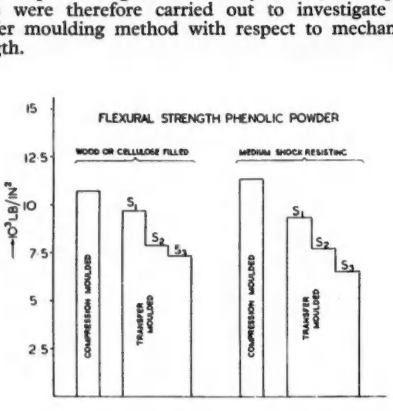


Fig. 1.

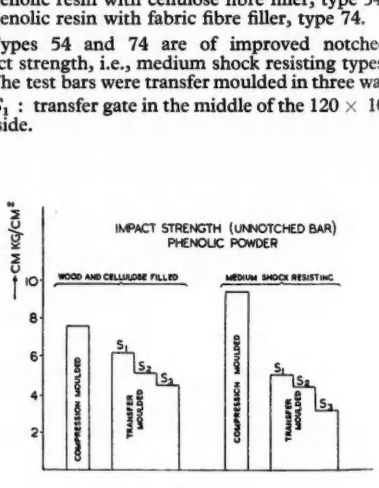


Fig. 2.

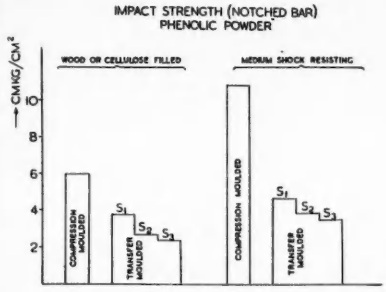


Fig. 3.

Bar S_2 : transfer gate at 30 mm. distance from end of bar.

Bar S_3 : at the end of the bar.

Figs. 1, 2 and 3 show a comparison of the average mechanical strength figures. The results are :—

(a) The mechanical strength of compression moulded specimens is superior.

(b) The difference in strength figures is significant with medium shock resisting powders with respect to unnotched and notched impact strength.

(c) The strength decreases by moving the transfer gate from the centre of the bar towards the ends.

To investigate the structure of the mouldings the specimens were cut lengthwise, ground, polished and etched. The investigation shows that with transfer mouldings there is a typical regular layer effect ; the fibres of the fillers are quite regularly distributed in concentric circles, and the centre of the system is opposite to the position of the transfer gate.

Fig. 4 shows the typical layers in the transfer moulded specimen in comparison with the compression moulded specimen (Fig. 5).

The sectional view of the transfer moulded specimens is similar to a spherical wave propagation at which the fibres of the filler are orientated in tangential direction.

With specimens where the transfer gate is in the middle, the strongest section is in the middle portion also. The strength of the specimen may be as strong or stronger than those of compression moulded specimens because the fibres are parallel to the test bar axis. When the transfer gate is nearer the ends, the orientation of fibres relative to the bar axis changes and some may lay perpendicular to the axis, and the strength is therefore reduced. In fact there is a large scatter with test bars S_2, and, where the gate is 30 mm. from the centre, fracture occurs at B, whilst with bars S_3 it occurs at C. (Fig. 4.) In the latter case the fibres are orientated perpendicular to the axis. Under mechanical strain the tensile stress acts perpendicularly to the particles. The shape of the particles will have little influence on the mechanical behaviour, and in practice only the resin will determine the strength of the specimen.

The test results as indicated in Figs. 2 and 3 are in conformity with these statements. The notched impact strength of the improved shock resisting types (54 and 74) is not materially better than the relatively

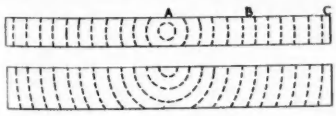


Fig. 4.

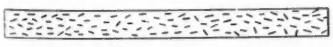


Fig. 5.

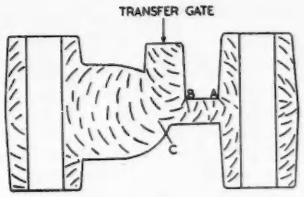


Fig. 6.

brittle types (31, 51 and 71), whilst the unnotched impact strength is lower.

To explain the cracks on the electrical insulator moulding a relatively complicated transfer moulding was investigated. The shape of the moulding is shown in Figs. 6 and 7. There are four outside threaded bosses in the transfer direction and two holes across. Surface treatment again shows the characteristic picture of spherical wave motion picture, with additional centres at A and B. Cracks occurred with this moulding at A and B., and the explanation of this may be uneven shrinkage. Measurements on test bar mouldings have shown that shrinkage is 50 per cent more if the particles are orientated nearly perpendicular to the bar axis. In the moulding shown in Fig. 6 there is a larger difference in shrinkage at A and B than at any other portion. The sections of Fig. 7 shrink less and possess sufficient strength to withstand the stresses. The cracks occur on the weakest section, that is, at A and B.

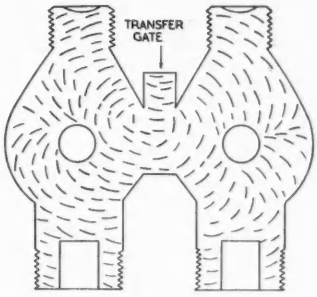


Fig. 7.

The explanation of the cracks on the above-mentioned insulator moulding is as follows :—

The transfer gate is in the middle of the molding on the cylindrical surface. A section through the cylinder parallel to the base reveals concentric circles opposite the transfer gate, and a rather irregular structure on the other side. There is a difference in shrinkage between the two portions of this sectional area, around the transfer gate in a direction tangential to the sectional area. The shrinkage is larger than on the opposite side, and consequently cracks occur parallel with the cylinder axis directed towards the centre of the body. The cracks appear in concentric circles around the transfer gate.

How to avoid cracks with transfer mouldings remains problematical, and considerable research will be necessary. Basically too much flow of the powder will have to be avoided and the easiest way to do this is to increase the cross-sectional area of the gate. With the above-mentioned insulator mouldings this change reduced the cracks considerably. It is also possible, by changing the position of the gate, to create an irregular structure at the critical sections. It remains for experimental investigation to show whether the use of more transfer gates would result in the interlocking of spherical wave motions in such a way that the resulting eddy flow will contribute to the required " irregular " structure of the moulding.

FRANCE

Correction of the Power Factor of Welding Machines by Condensers

By M. D. GENKIN. (From *Bulletin de la Société Française des Électriciens*, Vol. 6, No. 64, December, 1946, pp. 645-653, 5 illustrations.)

THE power factor of spot welding machines is known to be very low, namely in the order of 0·4 to 0·2, for large machines with long arms. Apart from this, the heavy current demands repeated at short intervals which are characteristic for the intermittent operation of these machines cause irritating fluctuations of light. These inconveniences, due to the essentially single-phase character of the load, make the machine's consumption difficult to tolerate on a distribution network.

However, a mitigation of these drawbacks by improving the power factor is possible and static condensers in series rather than in parallel connection have been suggested. The problem arises from the intermittent character of the load, the frequency of which may vary between 100 and 1,000 welds a minute, each of a duration of from 1 to 3 periods. Thus every time the circuit is made, a rush of current is produced which, with condensers in parallel may reach high intensities in the phase subsequent to the closing of the contacts. For a machine compensated for unity power factor by condensers in parallel, the line current, on making contact, may go up to the normal value of the non-compensated machine, i.e., 3 to 5 times that of the feeder, and this is an estimate based on the overcurrents due to the iron core. Contrary to this, if condensers in series are used, they are connected to the network only through the impedance of the machine.

Under resonance conditions the current equation may be written as follows :

$$i = \frac{E}{R}[Ke^{-\partial t}\cos(mt - \alpha) + \sin(\omega t - \varphi)],$$

the initial conditions being $t = 0$, $i_0 = 0$, $V_0 = 0$.

When the initial power factor varies from 0·4 to 0·2, m and k are contained between the following limits:

$$0{\cdot}97\ \omega < m < 0{\cdot}995\ \omega, \text{ and } 0{\cdot}9 < K < 1{\cdot}15$$

As a first approximation, m may be taken to be equal to ω, and k to unity, which neglects the decay factor ∂ preceding m. α then becomes equal to $\varphi - 90$ deg. and the current equation takes the well-known form

$$i = \frac{E}{R}\sin(\omega t - \varphi)(1 - e^{-\partial t})$$

The curves $I = \pm E/R\ (1 - e^{-\partial t})$ are those of the maxima of the current curve. From these it can be seen that the current intensity during the troubled operation does not exceed the value of the maximum for the continuous operation, and that even the latter is only gradually reached. This is in contrast with conditions in operation with parallel condensers.

In sustained continuous welding operations the occurrence of a transient makes only a negligible difference in the total heat of the current. This, obviously, is not so in the intermittent operation of spot welding, when the duration of an individual welding run does not always last even 2 to 3 periods. The effect of the wave form during the intitial alternations, on the heat of the current, can be estimated as follows : The total heat produced during the transient period of length t is

$$W_t = R\int_0^t i^2\,dt = R\int_0^t (i_t + i_p)^2\,dt$$

i_t being the transient, and i_p, the permanent term. Instead of computing W_t, which would be difficult because the duration of the transient is not accurately known, it is simpler to compare the amounts of energy converted into heat for an equal period under the transient and the permanent components. It is presumed that each could exist by itself from the moment of the closing of the contacts. Denoting the total current by i, the difference between the two quantities will be given by the integral

$$\Delta W = R\int_0^\infty (i^2 - i_p^2)\,dt \qquad .. \quad (1)$$

The integral has to be taken from 0 to ∞, because the transient component becomes negligible after the transient period in the practical sense of the term. With condensers in parallel the energy converted into heat in the machine is the same as it would be if the condensers were not used. The current absorbed by the machine is given by

$$i = \frac{E}{Z}\left[\sin(\omega t - \varphi - \psi) + \sin(\varphi + \psi)\,e^{-\frac{R}{L}t}\right]$$

for $e = E\sin(\omega t - \varphi)$, and $\tan\psi = L\omega/R$.

After obvious substitutions, the quantity ΔW may be cast into the form

$$\Delta W = LI^2\left[\frac{\sin^2(\varphi + \psi)}{2} - 2\sin(\varphi + \psi)\sin\varphi\cos\psi\right] \quad (2)$$

I being the amplitude of the permanent current. The actual circuit has, for the purpose of computation, been replaced throughout by a single equivalent circuit which does not contain iron with the lumped constants R, L, and C. The value of the bracketed expression in eqn. (2), for $\cos\psi$ between 0·2 and 0·7, and contact made at a phase angle between 0 and 90 deg., varies between the limits $-1{\cdot}0$ and $+0{\cdot}5$, so that the energy output in welding is either 0·5 LI^2 Joules greater, or LI^2 Joules smaller than the heat energy that would have been produced by the permanent current during the length of the transient period, if it could have existed by itself.

Under similar conditions, with series condensers, the current is given by

$$i = \frac{E}{R}\left[ke^{-\partial t}\cos(mt - \alpha) + \sin(\omega t - \varphi)\right] \quad (3)$$

By an analogous calculation

$$\Delta W = RI^2\left[\frac{1}{4\partial} - \frac{1}{\partial}\right] = -\frac{3}{4}\frac{R}{\partial}I^2 \qquad .. \quad (4)$$

An easy transformation yields

$$\Delta W = -1{\cdot}5\,LI^2 \qquad .. \quad .. \quad (5)$$

It is thus found that in a resonant series circuit the energy given out as heat during the transient period is always less, by 1·5 LI^2 Joules, than the energy supplied by the permanent current during the same period, if it could have existed by itself. This relation is independent on the phase angle of contact-making, and is only conditional upon the voltage being zero on the closing of the contacts.

In the intermittent operation of high-speed welding these differences are substantial. For a spot weld of 3 periods duration the energy turned into heat in permanent operation would thus be

$$W_{\infty} = RI^2{}_{\infty}T = RI^2\frac{3}{2}T = RI^2\frac{3\pi}{\omega}$$

During the period of the transient, with series condensers in circuit, the energy output is

$$W_t = RI^2 \frac{3\pi}{\omega} - 1{\cdot}5\,LI^2 = \frac{RI^2}{\omega}[3\pi - 1{\cdot}5 \tan \psi_0]$$

thus, for $\tan \psi = 2$, $(\cos \psi = 0{\cdot}446)$

$$W_t = 1{\cdot}5 \frac{RI^2}{\omega} 4{\cdot}28$$

or 68 per cent of the energy of the permanent current, and for

$$\tan \psi = 5, \quad (\cos \psi = 0{\cdot}195)$$

$$W_t = \frac{RI^2}{\omega}[3\pi - 7{\cdot}5]$$

or 20·4 per cent of the energy of the permanent current.

When connecting condensers in parallel with the machine, W_t, according to the phase of the contact-making, φ, and the power factor, ψ, within the limits indicated above, will lie between

$$\frac{RI^2}{\omega}[3\pi - \tan \psi] < W_t < \frac{RI^2}{\omega}\left[3\pi + \frac{\tan \psi}{2}\right]$$

for $\tan \psi = 2$ this becomes $0{\cdot}79\ W_p \leqslant W_t \leqslant 1{\cdot}11\ W_p$, and for $\tan \psi = 5$, $0{\cdot}47\ W_p \leqslant W_t \leqslant 1{\cdot}53\ W_p$, where W_p denotes the energy output (as heat) of the permanent current during the period $3p$.

The fact that in series connexion the full load output cannot be reached in intermittent operation does not preclude the use of this arrangement. Remedies are available either by allowing for this in laying out the machine, or by prolonging the welding period allotted to an individual spot. Both in parallel connexion and with a non-compensated machine, the heat produced during the initial periods varies according to the phase of the closing of contacts, which renders the control of high-speed welding precarious. Synchronous power factor control, therefore, is of particular interest, as may be mentioned in passing, because it results in the suppression of the transient current, particularly in the last-mentioned case. An economic advantage of the series arrangement over that in parallel may be seen in that the former does not need, as the latter does, special devices for maintaining an adequate residual static charge on the condensers during the interruption. The characteristics of the different arrangements, as established, among others, by M. Martin (Bull. S.E.V., 1945), and Levoy (Transact. A.I.E.E., 59, 1940, pp. 1002 ff.), may be described as follows : In non-compensated machines, an over-current of about 7 times the normal intensity follows the closing of the contacts, and may extend over several periods. When compensating the same machine by condensers in parallel, the overcurrents tangibly subside, but they do not disappear altogether. As a new feature, there is an additional high-frequency oscillation (of about 600 c/sec.) subsequent to the closing of the contacts. Owing to the presence of iron in the circuit, the variable current shows a marked assymmetry. This contradicts the assumption made above when treating the case by a simplified equivalent circuit. In reality, however, there is a voltage thrown suddenly on a transformer the magnetic circuit of which is liable to become saturated in the process. This leads to much higher overcurrents than those hitherto considered. The transient gives rise to an assymetrical component of the flux, the amplitude of which depends on the instant of circuit-making, and on the magnetic condition of the core. When series condensers are used, the aperiodic component in the current curve is entirely suppressed by the condensers which block the passage to the permanent component. Also, examination of the oscillograms reveals that the form of the current curve in subsequent spot weldings is much more uniform and independent of the variable initial voltage across the condenser terminals. This is the case even without synchronous control.

Table I gives the main characteristics of two circuits in continuous operation for a welding machine having the same power factor under two different assumptions. It is seen that according to whether the terminal voltage, or the line voltage, is taken as the reference voltage, the ratio of the capacities as well as that of the voltages at their terminals vary inversely. As the cost of the condensers for the same power rating falls with increasing voltage rating, it would seem that to use a capacity corresponding to the highest voltage should be the most economical solution. In practice, however, there is a different problem to solve depending on whether a new machine has to be installed, or the power factor of an existing one to be improved. In the latter case, the supply voltage is the same as the voltage at the machine terminals. Planning for a series arrangement,

TABLE I. Regulation of the Load by Varying the Transformation Ratio.

Number of turns	Initial power factor $\cos \psi = 0{\cdot}448$			Initial power factor $\cos \psi = 0{\cdot}196$		
	Fraction of load*	Live current	Power factor	Fraction of load	Live current	Power factor
			Condensers in series			
50	1	0·448	1	1	0·196	1
55	0·699	0·331	0·95	0·476	0·123	0·76
60	0·503	0·264	0·85	0·207	0·074	0·55
65	0·355	0·206	0·78	0·115	0·062	0·44
70	0·260	0·163	0·72	0·073	0·038	0·38
75	0·200	0·134	0·67	0·051	0·030	0·34
80	0·157	0·111	0·64	0·038	0·024	0·31
85	0·128	0·094	0·61	0·030	0·020	0·29
90	0·106	0·081	0·59	0·024	0·017	0·28
95	0·090	0·071	0·57	0·020	0·015	0·27
100	0·077	0·062	0·55	0·0166	0·0126	0·26
			Condensers in parallel			
50	1	0·448	1	1	0·196	1
55	0·828	0·403	0·92	0·828	0·242	0·67
60	0·693	0·415	0·75	0·693	0·330	0·41
65	0·592	0·452	0·59	0·592	0·417	0·28
70	0·510	0·494	0·46	0·510	0·499	0·20
75	0·445	0·536	0·37	0·445	0·553	0·16
80	0·390	0·573	0·31	0·390	0·602	0·13
85	0·346	0·606	0·26	0·346	0·644	0·11
90	0·308	0·635	0·22	0·308	0·680	0·09
95	0·277	0·660	0·19	0·277	0·709	0·08
100	0·250	0·681	0·16	0·250	0·736	0·07

* Fraction of full-load currents of the non-compensated machine.

the condensers have to be designed for a voltage higher than that of the network, which entails their being more economical than parallel condensers but necessitates the insertion of a special auto-transformer, so that in the end there is little to choose between the two solutions. Yet, in the case of a new machine the design and winding of which can be adapted to the requirements of the series arrangement, the economic advantage is indisputable.

The regulation of welding machines is usually obtained by tappings on the primary winding of the welding transformer. When the transformation ratio is n/n_1, the powers are in the ratio $(n/n_1)^2$. Neglecting the losses and the magnetizing current of the transformer the constants referred to the primary winding are : $n^2 L\omega$, n^2R, and n^2Z, where R, $L\omega$, and Z, are the constants of the secondary circuit. If unity power factor has been realized for a tapping embracing n turns, it is for parallel condensers,

$$C\omega - \frac{L\omega}{n^2Z^2} = 0$$

and for a tapping after n_1 turns, $C\omega \frac{L\omega}{n_1^2 Z^2} \lesseqgtr 0$. When $n_1 > n$, the whole circuit of the machine and the condenser battery will act as a capacitive reactance ; and when $n_1 < n$, it will act as an inductive reactance. As in this arrangement unity power factor applies for full load current, the current at fractional loads will have an angle of lead which becomes greater, as the load is lower. This suggests the provision of similar tappings for regulation on the condenser battery, to keep the current intensity within safe limits, or to improve the the power factor only to a value less than unity.

In the series arrangement, when cos $\varphi = 1$ for a number of turns, n, we have

$$n^2 L\omega - \frac{1}{C\omega} = 0$$

When proceeding to n_1 turns, this relation becomes

$$n_1^2 L\omega - \frac{1}{C\omega} = (n_1^2 - n^2) L\omega \lesseqgtr 0$$

according to whether $n_1 - n$ is positive o · negative. When $n_1 > n$, the circuit behaves inductively, and thus with increasing n_1 the load diminishes, the angle of lag increases, and, in contrast to the former case, the current decreases. There might be a certain interest in compensating the machine for a slightly leading power factor at full load to enable the overall power factor for the maximum current demand to be improved, this latter referring to the whole installation including non-compensated machinery also. Regarding regulation of the load proper in a parallel arrangement, this is obtained by tappings strictly as in non-compensated operation. Yet in a series arrangement the tappings on the transformer primary have to be much closer to each other to offer the same facilities for regulation.

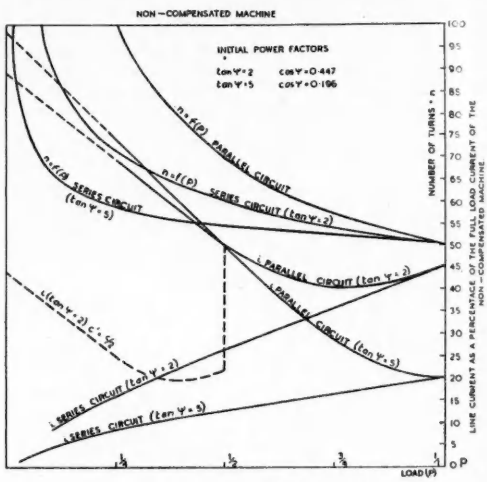

NON-COMPENSATED MACHINE
INITIAL POWER FACTORS
tan Ψ=2 cos Ψ=0·447
tan Ψ=5 cos Ψ=0·196
n=f(p) PARALLEL CIRCUIT
n=f(p) SERIES CIRCUIT (tan Ψ=2)
n=f(p) SERIES CIRCUIT (tan Ψ=5)
PARALLEL CIRCUIT (tan Ψ=2)
PARALLEL CIRCUIT (tan Ψ=5)
SERIES CIRCUIT (tan Ψ=2)
SERIES CIRCUIT (tan Ψ=5)
I(tan Ψ=2) C=½
NUMBER OF TURNS = n
LINE CURRENT AS A PERCENTAGE OF THE FULL LOAD CURRENT OF THE NON-COMPENSATED MACHINE
LOAD (p)
O P

Fig. 1. Constant voltage supply.

Variation of the line current and of the load on the machine as functions of the number of turns, referred to normal load compensated for unity power factor, corresponding to 50 turns.

Table II and Fig. 1, respectively, show the variations of the current and the number of turns for two machines on a load basis. One of the machines has an initial power factor of 0·2 (tan $\psi = 5$), the other, of 0·45 (tan $\psi = 2$). The rapid increase of the current with decreasing load in the case of the parallel arrangement is striking. The branch of the curve in broken lines represents the intensity of the current obtained by suppressing half of the condenser battery from half-load on. Apart from this, it is seen on the curves of the number of turns plotted against load that, for tan $\psi = 5$, in the parallel arrangement it is necessary to double the number of turns to reduce the load to one quarter, whereas the same effect is obtained in the series arrangement by augmenting the number of turns by a mere 15 per cent. When regulation by auxiliary tappings is arranged for on an auto-transformer inserted between the network and the machine with its series condensers, instead of on the transformer of the machine itself, the passage from one tapping to the next will not cause any change of the overall power factor of the assembly, which thus remains at unity

TABLE II.

	Terminal voltage of machine V	Condensers			Line	
		Capacity μF	Voltage V	kVA	Current A	cos φ
Condensers in series						
Normal operation	734	3100	699	477	680	1
Short-circuit operation	843	3100	880	756	860	0–73
Normal operation	587	6360	430	365	850	0·8
Short-circuit operation	730	6360	585	685	1170	0·54
Condensers in parallel						
Normal operation	735	2610	735	477	680	1
Short-circuit operation	735	2610	735	477	810	0·767
Normal operation	587	3280	587	365	850	0·8
Short-circuit operation	587	3280	587	365	985	0·64

NOTE.—In this Table the parallel arrangement is presumed to be supplied through an auto-transformer to obtain the same voltage at the machine terminals as in the series circuit.

whatever the load. Regulation is no more difficult than that of the current due to a variable voltage by means of a (variable) resistance.

Synchronous regulation can be applied to compensated machines without any difficulty. As mentioned before, the series arrangement of condensers has, here, an economic advantage over the parallel arrangement by not necessitating special elements for maintaining the correct residual charge during the successive interruptions.

RUSSIA

Deep Nitriding of Cutting Tools

By B. I. KOSTETSKY and G. D. KURUKLIS. (From *Stanki i Instrument*, No. 6, 1946, pp. 16–19, 11 illustrations.)

WITH nitriding, or gas cyaniding, of high speed steel cutting tools at 530–550 deg. C. for about two hours, a surface hardness in the order of Vickers Nos. 1090–1200 is obtained, but the depth of the case, or hard surface is only 0·0008 to 0·0025 in. It is, therefore, only useful to a very narrow range of tools, i.e., to those intended for light cuts and having a profile, which requires grinding on the front only.

The Ural Machine Tool Works have carried out a series of tests with nitrided cutters of their own and other makers' manufacture and have found their performance most inconsistent, sometimes no better than that of untreated tools.

It appears from examinations of material near the cutting edge, after grinding and honing, that the main cause of failure is the insufficient depth of the hardened layer. During grinding and honing, locally hardened austenite and martensite structures are formed and the wear-resisting tempered martensite is converted to troostite. These changes involve local strains and plastic deformation of surface grains takes place under the action of the abrasive.

The thickness of metal affected by these surface influences is between ·0004 and ·0025 in. so that most of the treated metal may be regarded as damaged and likely to give faulty service. Furthermore, an analysis shows that "primary" wear, taking place within a very short time of the commencement of service and extending for about ·02 to ·03 in. of the back profile of the tooth, is of the order of ·002 in. to ·003 in. in depth. Thus near the cutting edge the hardened metal is removed at the very beginning of the cutter life.

PREPARATION OF SURFACE.

To obtain deeper penetration of nitrogen it was found essential to perfect the de-greasing technique. The various methods of cleaning the surface may be classified as mechanical, chemical and electrochemical, but it was soon found that the former two were unsatisfactory. E.g. electrochemically treated surfaces after $2^1/_2$ hours treatment were on the average, harder by 100 on the Vickers scale and had 40 per cent deeper penetration than those cleaned with paraffin.

The usual method of electrochemical de-greasing is to position the work at the cathode in a solution of 3 to 15 per cent of caustic alkali, but the process chosen was rather different as is described later.

THE USE OF CATALYSTS.

Nitrogen penetration can be increased by the judicious use of auxiliary elements to help the activated atoms of nitrogen and carbon to diffuse into the metal. The essence of the nitriding process is as follows :

During the split-up of molecules of methane (CH_4), which is the main component of the process gas, and of ammonia (NH_3), we obtain nascent atoms C^1 and N^1 :

$$CH_4 \rightleftarrows C^1 + 4H^1$$

$$NH_3 \rightleftarrows N^1 + 3H^1$$

The development of these reactions depends on the temperature, pressure and gas velocity. It is practically uninfluenced by the composition of the metal.

On the other hand, the ability of the metal to be affected by the gases, depends on its composition, structure and condition of the surface. The general form of the reactions is :

$$mMe + nNH_3 \rightleftarrows Me_m N_n + 3nH$$

$$m_1 Me + n_1 CH_4 \rightleftarrows Me_{m_1} C_{n_1} + 4n_1 H$$

When *Me* is any metallic element in the steel capable of forming nitrides and carbides.

It is clear that together with the nitrogen and carbon atoms, a great deal of active hydrogen is liberated, which has been shown by Fisher and others to be detrimental to the development of the process. According to these authorities the presence of hydrogen reduces the depth of nitrogen penetration, reduces hardness, increases brittleness, and hastens de-carbonization. It is reasonable to suppose, therefore, that to improve results one must remove the hydrogen.

In this connection the Ural Works carried out a series of experiments in which the process was conducted in the presence of shavings of various hydrogen-absorbing metals. It was found that the best results were obtained when these were of aluminium. The results are shown in Figs. 1–3. Copper shavings gave a negligible improvement.

The experiments were carried out on plates $^3/_8 \times {}^3/_4 \times 4$ in. and after treatment they were cut at an angle of 1 deg. 10 min. to the surface to give very gradual variation of depth. Two different steels ("R.F.1" and "E.I. 262") were tested giving very similar results. The micro-analysis showed that white grains began to appear

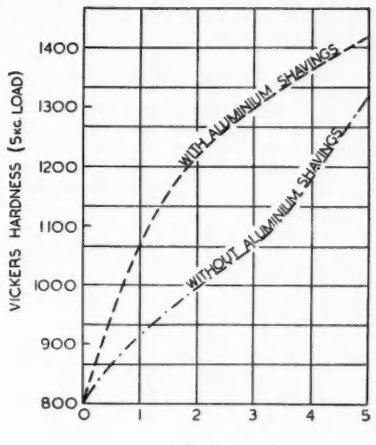


Fig. 1. Relation between hardness and length of nitriding treatment.

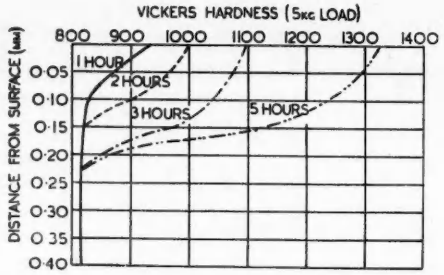


Fig. 2. **Hardness at varying depth below surface with treatment of varying duration: no aluminium shavings.**

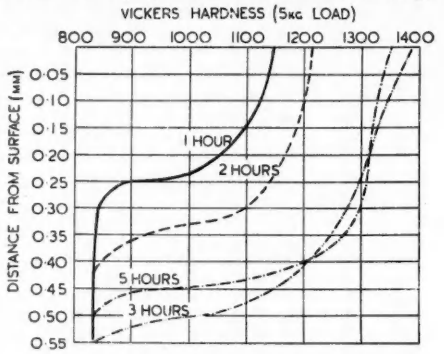


Fig. 3. **Hardness at varying depth below surface with treatment of varying duration: with aluminium shavings.**

only after a 5 hour treatment and an examination of Vickers pyramid impressions did not reveal any signs of brittleness.

PROCEDURE.

The final procedure adopted was as follows :

The cutter, after hardening, tempering and final grinding was hung from the cathode of an electrolytic bath containing 1·5 per cent $NaOH$, 2·5 per cent NO_3CO_3 and 0·2 per cent dextrin. The bath was of welded steel. The temperature was 18–20 deg. C. Current density was ·13 to ·3 amps per sq. in. and the time 5 mins. The anodes were iron plates coated with nickel, which is practically insoluble in the electrolyte. After de-greasing the cutter was washed for 2 to 5 mins. in hot water and dried. The effectiveness of de-greasing could be checked by the appearance of the wetted surface.

Nitriding was carried out in the usual type of furnace but at a higher temperature, 550–600 deg. C., and for a longer time : i.e. 3–4 hours. The cutter was covered by a thin layer of aluminium shavings which were renewed after each application. Coke-oven, pyrolysis or oil gases could be used, with 20 to 40 per cent ammonia. The muffle furnace was kept under a pressure equal to 1 to 2 in. water column.

The resulting layer was ·012 to ·024 in. thick and of 1100–1300 Vickers hardness. The thickness varied, of course, with the type of cutter.

TESTS IN SERVICE.

A great number of cutting tools of all kinds were treated by this new process and tested under ordinary production conditions, and the table below is typical of the results obtained. Two different types of tool steel, R.F. 1 and E.I. 262 were tested, treated by the ordinary process and alternatively by the process of deep penetration in the presence of aluminium shavings. The tool was a $2^3/_8$ in dia. thread-milling cutter with a cutting speed of 43 ft./min. and a feed of 0·0044 in. per tooth. The coolant used was quenching oil. In all cases the wear allowed before re-grinding was ·02 to ·03 in., measured along the back profile of the tooth. It will be seen that the average length of service of cutters treated by the new process was over four times as long as those treated by the old process and, moreover, the performance of the tools varied by less than 25 per cent.

TABLE.

COMPARATIVE RESULTS WITH A THREAD MILLING TOOL.

Tool Serial No.	Number of jobs done between sharpenings.					
	First Run.	After re-sharpening.				Average
		1	2	3	4	
TEST A.						
Steel Quality R.F.1. treated by deep penetration process.						
I–43	56	67	72	58	68	64
I–47	65	81	76	69	74	73
I–49	69	68	75	66	68	65
I–51	82	70	72	68	65	71
Steel Quality R.F.1. with ordinary heat treatment.						
I–53	13	16	15	13	12	14
I–54	10	20	19	17	15	18
I–57	21	17	14	18	22	18
I–58	17	18	14	15	15	16
TEST B.						
Steel Quality E.I.262. treated by deep penetration process.						
I–61	82	78	74	68	73	73
I–65	72	76	69	76	66	71
I–67	66	71	65	68	72	70
I–68	75	72	62	66	63	67
Steel Quality E.I.262. with ordinary heat treatment.						
I–71	14	16	15	13	12	14
I–72	18	16	19	15	13	16
I–76	22	18	21	17	13	18
I–77	18	15	18	16	14	16

Similar practical tests of length of life with all kinds of milling cutters, slotting and shaping tools, drills and taps have shown that the deep penetration method is particularly advantageous when the tools are to be used without coolants and for the processing of alloy and extra-high strength steels with Brinell hardness numbers of 250 to 320. For such work the increased resistance to wear is in the order of 550–600 per cent.

In the more normal machining processes, i.e., when a coolant is used and the material to be cut has a Brinell hardness of 150 to 250, the life of the tool is generally increased by some 350–400 per cent as compared with tools hardened in the ordinary way.

CONCLUSIONS.

1. An analysis of the condition of the surfaces of tools after grinding and of the way in which wear takes place indicate that the comparative ineffectiveness and narrow limits of existing methods of nitro-cementation are due to insufficient depth of penetration (·0008 to ·0025 in.).

2. To increase wear resistance and to make the process applicable to a bigger range of tools, it is necessary to obtain deeper penetration.

3. Increased penetration can be obtained : (a) by removing from the "cyaniding" gas its active hydrogen atoms which interfere with the penetration of nitrogen and carbon ; this can be effected by the introduction of aluminium shavings as a catalyst : (b) by the use of electro-chemical cleaning to ensure a very receptive metal surface.

4. The method perfected by the authors results in a nitro-cementation as deep as ·012 to ·020 in.

5. The depth so obtained shows no tendency to excessive brittleness.

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The Ellira Welding Process *

By. W. RÄDEKER. (From *Stahl und Eisen*, Vol. 66/67, No. 3/4, January 30, 1947, pp. 42-48, 14 illustrations.)

EXPRESSED in terms of metal deposited per minute, welding output depends on the current intensity, and as shown by workshop tests it does not matter whether welding is done by hand or by d.c. automatic machine. The electrode diameter too is only of secondary importance. When changing over from manual to automatic welding human physical limitations are overcome, and electrodes beyond 5 mm. diameter can be used continuously. Fig. 1 shows the limiting current intensity in amps per sq. mm. which causes electrodes of various diameters to glow and thereby makes correct welding procedure impossible.

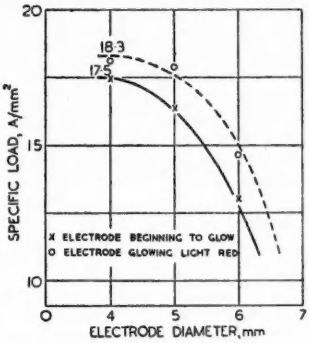


Fig. 1. **The upper limit of specific current load for coated electrodes.**

To overcome these restrictions the welding procedure had to be modified as follows :

(1) Heat effects in the wire electrode increase with its length. The connexion to the electric current must therefore be arranged close to the weld.

(2) Short length of electrodes would produce irregularities in the weld through interruptions. Electrodes in coils are required, fed in at properly regulated speed.

(3) Coated electrodes would suffer from coiling and uncoiling and the coat material must therefore be separated from the core wire. Granulated powder takes its place. It is added during welding and is fused in by the welding heat.

For longitudinal welds the control gear head is moved horizontally over the work at a speed approaching 800 mm. per minute. For circumferential welds the work itself is rotated under the static head. All movements must be smooth and as free as possible from jerks, and the essential conditions for satisfactory welds are therefore : sufficiently large motors, well regulated current, and amply strong suspension of the head to ensure freedom from vibrations.

The electrode wire is fed over electrically driven rolls and, as the arc voltage depends on its length, this fact is utilized to regulate the motor. With longer arc and increased voltage the rod feed speed goes up. The wire jaws connect the current to the electrode and the flux powder is fed on to the joint ahead of the electrode, the end of which is completely covered by the powder. The current is a.c., transformed to up to 4000 amps. and 25 to 60 Volts, and current and feed speed are regulated by the control gear.

For manual welding the current can be increased in linear proportion to the rod diameter. With the Ellira process, however, the current is increased as the square of the rod diameter, i.e. in proportion to the cross-sectional area of the wire, which takes a specific load of 25 to 50 amps. per sq. mm. This means a considerably higher current for the same diameter electrode, as shown in Fig. 2. In consequence a remarkable increase of welding output is possible.

Regarding the method of welding it was originally assumed that the molten slag was heated to more than 2700 deg. C. by the electric current which, in turn, heated up the fusion faces and the molten metal. The present opinion, however, is that primarily the process is genuine arc welding, and that only 10 to 15 per cent of the energy input goes into the heating of the slag.

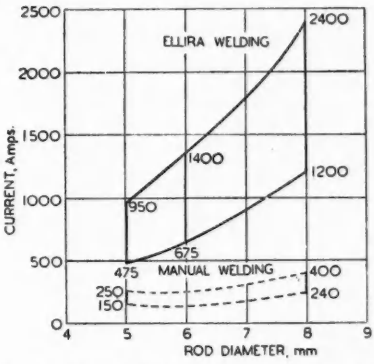


Fig. 2. **Specific amperage for manual and Ellira welding.**

This view is supported by electro-chemical considerations, based on observed temperatures of more than 2700 deg. C. in the centre area of the molten pool. American calculations arrive at about 3000 deg. C. as the temperature of the " melt ". Even higher temperatures can be assumed, however, from measurements and the following considerations. One unit of weight of the welding rod will melt two units of weight of the base metal and, therefore, the calorific contents of the overheated rod must at least be equal to the calorific contents of the triple size molten pool. From the heat necessary, including melting the powder, a temperature of more than 4000 deg. C. can be calculated for the rod, and this is at least as high as the temperature of the arc itself.

Because of the marked concentration of heat in immediate proximity to the arc about two volumes of parent metal are fused for each volume of welding rod. The composition of the parent metal is therefore reflected in the weld analysis. With comparatively few types of welding rod the requirements of a great variety of parent materials can be satisfied, and the composition of the weld can be anticipated without difficulty and with considerable accuracy.

For the same reason edge preparation for butt welds of plates of more than 50 mm. (2 in.) thickness need not go beyond an angle of 30 deg., but an angle of 60 deg. is required for single-V joints in 10 mm. ($\frac{3}{8}$ in.) plates. Fig. 3 illustrates this point for various types of joints. For joints to be welded from one side only a 3 mm. ($\frac{1}{8}$ in.) root face will allow close and accurate alignment, thus preventing the escape of molten metal through the gap. A copper backing strip can be used in addition, pressed against the parent plates, but this is not neces-

* This process is known as the Submerged Arc or Unionmelt process, both in the U.S.A. and in Great Britain. Valuable data for the welding of plates up to 6 in. thick are given in R. R. Sillifant's article in Welding, London, January, 1946, and more specialized applications are described in two articles in *The Journal of the American Welding Society*, April, 1947.—EDITOR, E. D.

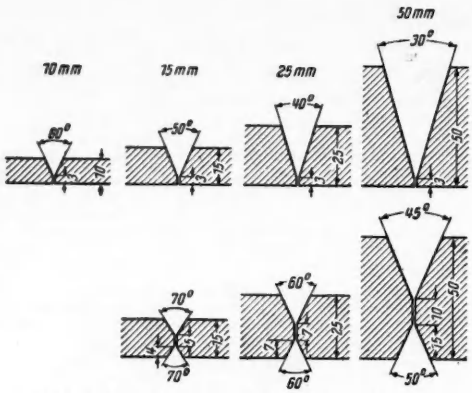


Fig. 3. **Plate edge preparation for Ellira welding.**

sary with joints of the double-V type, although the root face should be more than 3 mm., and any gap between the root faces must not exceed 0·7 mm.

These requirements for accurate edge preparation have been rather a hindrance to the large scale application of the new process to plate and pipe work, but less so in shipbuilding and structural work where fillet welds play a prominent part. Recently, the Ellira process has been combined with hand or automatic welding, and it is being applied from both sides as shown by Fig. 4 which relates to the combination of hand welding from below and Ellira welding from above, with the latter carried out in one run. This procedure has the advantage of easier edge preparation, and no cutting away at the root face is necessary, because this portion of the deposited metal is thoroughly fused in by the following Ellira run, which eliminates any oxide inclusions and considerably facilitates, for example, the welding of circumferential seams. Manual welding is usually provided for about $\frac{1}{4}$ to $\frac{1}{3}$ of the plate thickness and a gap up to about 2 mm. is acceptable for this, but the depositing of sufficient metal for up to $\frac{1}{3}$ of the plate thickness is laborious and has a marked influence on cost.

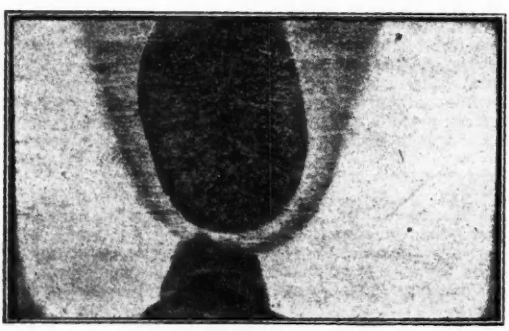


Fig. 4. **Combination of manual welding (bottom) and Ellira welding in one run (top).**

It is therefore recommended that the procedure should be in three stages as illustrated by Fig. 5. First, the root of the larger V is welded with a low current to avoid penetration to the other side and, secondly, the smaller V is welded with a high current to make sure that the previously welded root is again fused. Thirdly, the welding of the larger V is completed. This procedure, however, whilst thoroughly sound, has the disadvantage that the workpiece must be re-clamped twice between the welding operations, because the Ellira

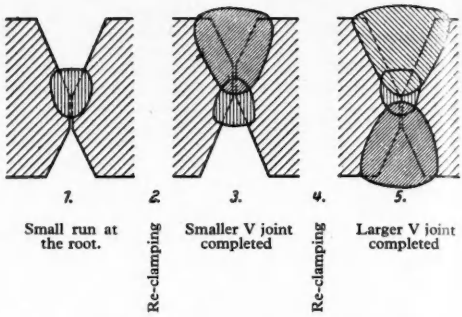


Fig. 5. **The three stages in butt welding a double-V joint by Ellira welds only.**

process cannot, of course, be applied to an overhead position.

Great care must be given to the welding powder as well as to the coating material on manual-welding electrodes. The powder consists of metasilicates of calcium, aluminium and magnesium, with some fluorites and its granulation varies according to the plate thickness, the finest powder being used for the thickest material. Some trouble is still experienced because it is hygroscopic, which results in porosity of welds, but this can be avoided by carefully drying the powder before welding. It should be stored in leak-proof containers. Similar troubles are due to tiny impurities mixed with the powder, e.g. wood splinters which contain a certain amount of water which would cause porosity. Therefore steel barrels are recommended for powder storage, instead of wooden boxes.

The molten pool forms a shield against the atmosphere; there is no absorption of nitrogen from the air, no loss of alloy elements through oxidation, and no loss by spatter. Thus chromium, nickel, molybdenum, copper, phosphorus and sulphur are not absorbed into the slag, but pass in unchanged quantities into the weld. A small amount of silicon, however, is reduced and goes into the weld whilst the oxygen content of the silica escapes as carbon oxide, thus producing porosity in the slag. This, however, must not be taken as an indication of the presence of harmful gases. Compared with the quantity of deposited electrode metal the quantity of slag is about 80 to 100 percent, whilst with heavily coated electrodes the ratio is only 30 to 75 per cent. In contrast to electric arc welding the period required for solidification of the Ellira weld is about one minute, and this comparatively long time is an advantage by allowing for the separation of the slag from the weld metal and for elimination of impurities.

With the Ellira process two features contribute to the improvement of the metallurgical qualities of the weld: first, the very high degree of overheating of the melt which simultaneously excludes atmospheric influences, and secondly the depositing of the whole weld in one run. The highly liquid melt allows separation of all components having only slightly different specific gravities, especially the non-metallic inclusions and there is no danger of these inclusions collecting between individual layers as so often happens with manual welding.

Lack of penetration between deposited metal and the fusion faces, which is one of the risks with manual welding, is not a trouble with the Ellira process because the fusion of the parent metal edges is complete. Plates showing considerable slag inclusions are freed from these in the fusion zone, thus proving the good effect of the overheated melt.

The whole melt solidifies as one piece and this may

cause certain dangers. Following the escaping heat crystals are formed standing on edge on the fusion faces, meeting in the centre of the weld, and any slag inclusions will be urged towards this region. Even so, no reduction of physical properties has been shown for the centre zone, except by Izod tests which gave higher values near the fusion faces indicating higher density there than at the centre part.

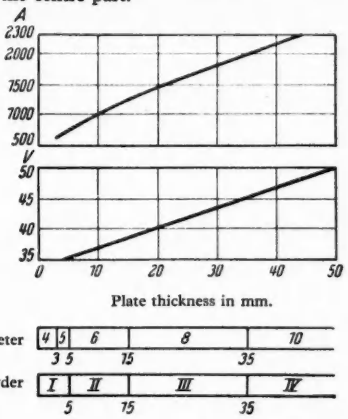


Fig. 6. **Voltage, amperage, rod diameter and powder granulation for various plate thicknesses.**

Based on the wide experience of many workshops a set of rules for the Ellira welding procedure has been developed. Fig. 6 gives the upper limiting values for voltage, amperage, rod diameter and powder granulation, and both single-V and double-V welds are covered. With the latter, the graph figures are to be read for $\frac{1}{3}$ and $\frac{2}{3}$ of the plate thickness respectively (as illustrated in Fig. 5).

Higher current, using the same voltage, produces deeper welds and increases the welding speed. This is shown in Fig. 7. Higher voltage, however, results in greater width of the weld, which should be kept between 1·25 and 1·50 times the plate thickness. Surplus lengths of welding cable must not be kept in coils as this may result in induction, reduced welding current, and less welding output.

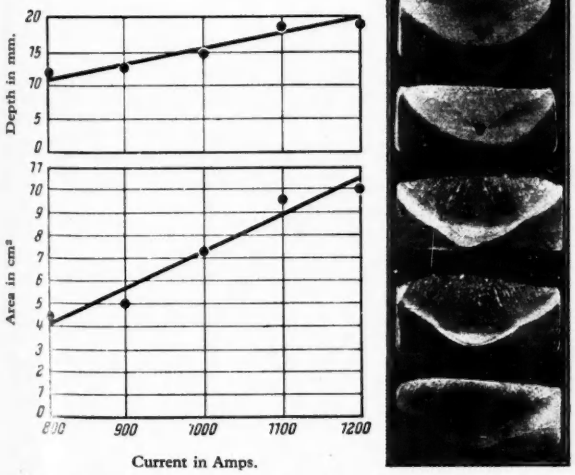


Fig. 7. **The effect of amperage on the depth and cross-sectional area of the weld.**

The physical properties of Ellira welds are the measure of the quality obtained, but annealing is only required when high Izod values are important and residual stresses have to be eliminated. Comparison between manually made welds and Ellira welds shows slightly lower tensile values for hand welded specimens because of the reduction of their manganese and silicon contents. Elongation and Izod values are somewhat higher with Ellira than with manually made welds and Izod test results indicate that the weaker zone is at the fusion faces for hand welding, but at the centre for Ellira welds.

The Ellira process also offers advantages in the welding of alloy steels which may produce cracks and other difficulties when using the slower manual or automatic processes and this applies especially to chromium steels. Copper-nickel steels with 1 per cent Cu and 0·5 Ni and austenitic chromium-nickel steels have been successfully welded.

Tensile test results from specimens with lateral welds allow only limited conclusions regarding behaviour under service conditions and a test to destruction by internal pressure was therefore carried out on a 4·5 m. long cylindrical vessel of 870 mm. internal diameter and 10 mm. wall thickness. The steel was of 37 kg/mm² ultimate tensile strength and 18 kg /mm² yield point. The vessel had a calculated permissible working pressure of 19 atmospheres and burst under a hydraulic pressure of 82 atmos., i.e. nearly 4½ times the working pressure. The circumference showed an elongation of 170 mm. and the fracture originated in the weld, but extended into the parent metal.

If chemical resistance is to be investigated, individual zones exposed to chemical action would not provide the right conclusions and it is preferable, therefore, to prepare specimens incorporating a complete welded joint and to study their behaviour to chemical action. If a comparison is made of the behaviour of gas welded, arc welded, and Ellira welded butt joints exposed to chemical corrosion the Ellira welds appear markedly superior.

Naturally, there are all kinds of defects to be expected if the Ellira welding process is not applied as it should be. Cracks must be avoided, and this means that stresses have to be kept to the minimum, but there are no general rules on how to do this. Practical experience and tests show the way. Sometimes the width of the weld needs increasing by using higher voltage, but in other cases the welding speed must be reduced to allow the shrinkage stresses to adjust themselves while the metal is hot. In difficult cases high alloy wire with 3 per cent manganese may solve the problem.

It may justifiably be claimed that the Ellira process effected a revolution in welding technique, and therefore it may be asked in which direction further developments are to be expected. At present, with a specific load on the electrode of 50 amps. per sq. mm., the welding speed is such that a further increase might make it difficult to control the amount of heat suddenly appearing in the melt. There is one exception, however, for which this superfluous heat is used to good effect, i.e., in the repair of steel castings by welding. With the orthodox practice of welding repairs for castings there is a risk that the finer branches of cracks will not properly be fused and filled with weld metal. With the Ellira process the specific load on the electrode has in such cases even been increased to 80 amps. per sq. mm. and the rod feeding speed to 3 metres per minute. It remains to be seen

whether the increase in local heat concentrations will not cause higher cooling stresses and perhaps cracks but normalizing immediately after welding will reduce or eliminate such shrinkage stresses.

With Thomas steels which are liable to produce lateral cracks, further investigations will be necessary until satisfactory welds can be produced.

Regarding plate thickness it is rarely required to go beyond 80 mm. and such thicknesses have been successfully welded. Until recently, 8 mm. was considered to be the low limit, but 3 mm. plates are said to have been satisfactorily welded.

Developments are also to be expected regarding the welding powder which goes into the melt. According to recent investigations the molten slag is no longer considered as an important medium for transmitting the electric current and the heat. Its composition can therefore be adjusted to follow metallurgical requirements. In the case of Thomas steels it may be possible to dispose of the sulphur and phosphorus contents and reduce the loss of manganese. Simplifying the powder composition would be of considerable value, because the powder weight represents 80 to 100 per cent of the weight of molten metal, and an even higher percentage of its volume.

Improved types of welding heads are also being developed, one of them for the internal welding of tubes of about 550 mm. inner diameter.

SWITZERLAND

Stabilization of Synchronous Generators by Rapid Regulation of Excitation in Power Transmission Over Long Distances

By W. FREY. (From *Brown Boveri Mitteilungen*, Vol. 33, No. 11, November, 1946, pp. 335-347, 8 illustrations.)

(*Concluded from September issue.*)

V. THE MACHINE WITH REGULATION ON BOTH AXES.

The reason for considering a two-axis machine is that according to the static condition $K > |\cot an\ \vartheta_0|$, for large values of ϑ_0 the factor K which determines the power becomes very large, to such an extent that at 180 deg. stabilization is impossible. The excitation power increases to infinity with larger pole-wheel angles because, when the pole-wheel voltage is increased, only the component which is perpendicular to the terminal voltage $\mathbf{U}$ is effective. Regulation on both axes is therefore required in extreme cases.

The rotor will be assumed to be fully symmetrical relative to both axes. This means that we can eliminate the factor $(p + \tau')$ in both terms of the basic equation (9), and the subscripts h and q are then no longer necessary. As in the case of equation (11) we can write :

$$\left.\begin{aligned}\xi_6 &= (K_{16} + pK_{26})\,X_5\\ \xi_7 &= (K_{17} + pK_{27})\,X_5\end{aligned}\right\} \quad .. \quad (20)$$

Putting (20) into (9) we obtain as previously the characteristic equation :

$$\frac{p^3}{\Omega^2} + \tau'\frac{p^2}{\Omega^2} + (\cos\vartheta + A + \tau' K_{20})\,p + \tau'(\cos\vartheta + K_{10}) = 0 \quad (21)$$

where

$$\left.\begin{aligned}A &= \mathrm{U}(1-\sigma)/E\sigma\\ K_{10} &= K_{16}\sin\vartheta + K_{17}\cos\vartheta\\ K_{20} &= K_{26}\sin\vartheta + K_{27}\sin\vartheta\end{aligned}\right\} \quad (22)$$

Equation (21) is constructed in the same way as equation (13). Therefore there will again be three cases, α, β and γ, corresponding to the stability conditions

$$\left.\begin{aligned}&\cos\vartheta_0 + K_{10} < 0\\ &A + \cos\vartheta_0 + \tau' K_{20} > 0\\ &A + \tau' K_{20} - K_{10} > 0\end{aligned}\right\} \quad .. \quad (23)$$

The distribution of the regulating intensities on the two axes remains arbitrary provided (22) is taken into account. To obtain the most favourable distribution we substitute :

$$\left.\begin{aligned}K_{16} &= K_1\sin\Psi_1\ ; \quad K_{17} = K_1\cos\Psi_1\ ;\\ K_{26} &= K_2\sin\Psi_2\ ; \quad K_{27} = K_2\cos\Psi_2\end{aligned}\right\} \quad (24)$$

To obtain a measure of the total power required for regulation we can take the two sums of the squares :

$$\left.\begin{aligned}K_{16}^2 + K_{17}^2 &= K_1^2\\ K_{26}^2 + K_{27}^2 &= K_2^2\end{aligned}\right\} \quad .. \quad (25)$$

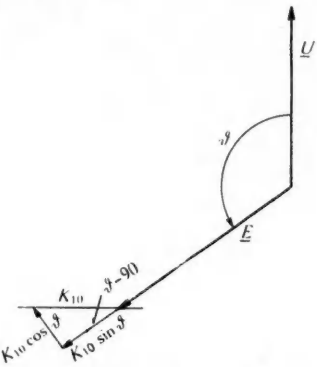


Fig. 6. Vector diagram of the pole-wheel voltage of a synchronous machine regulated on both axes.

Therefore the distribution of regulation on the two axes shall be chosen in such a way that K_1 and K_2 will be as small as possible. This is the case for :

$$\Psi_1 = \Psi_2 = \vartheta \quad .. \quad .. \quad (26)$$

Then

$$\left.\begin{aligned}K_{16} &= K_{10}\sin\vartheta\ ; \quad K_{17} = K_{10}\cos\vartheta\\ K_{27} &= K_{20}\sin\vartheta\ ; \quad K_{27} = K_{20}\sin\vartheta\end{aligned}\right\} \quad .. \quad (27)$$

The relations (27) are illustrated in the vector diagram of Fig. 6. The voltage variations are proportional to the values of K_{16}, etc. The vector diagram shows that with the distribution on the two axes which has been chosen, the resultant voltage increase from both axes is perpendicular to the terminal voltage $\mathbf{U}$. This is the most effective stabilization, since as already stated, only the component perpendicular to $\mathbf{U}$ has a stabilizing effect.

VI. STABILITY OF THE MACHINE ON THE LINE.

The theory will now be extended to cover the conditions of a machine coupled through a power-line to the network. As a result of the assumption that the frequencies of the compensating processes are low relative to the network frequency, the vector diagram can be regarded as valid at any given instant. The variables of the power-line are determined by the following

equations :

$$\left.\begin{aligned} \mathbf{U}_2 &= \cos \Phi\, \mathbf{U}_1 - jZ \sin \Phi\, \mathbf{I}_1 \\ \mathbf{I}_2 &= -\frac{\mathrm{j}}{Z} \sin \Phi\, \mathbf{U}_1 + \cos \Phi\, \mathbf{I}_1 \end{aligned}\right\} \quad .. \quad (28)$$

The machine is defined by

$$\mathbf{U}_1 = \mathbf{E}_1 - jX\mathbf{I}_1 \quad .. \quad .. \quad (29)$$

These equations (28) and (29) give :

$$\mathbf{U}_2 = \mathbf{E} \cos \Phi - \mathrm{j}X \frac{\sin (\alpha + \Phi)}{\sin \alpha} \mathbf{I}_1 \quad .. \quad (30)$$

with $\tan \alpha = X/Z$.

The following relations will be introduced :

$$\mathbf{E} \cos \Phi = \mathbf{E}^\star$$

$$X \frac{\sin (\alpha + \Phi)}{\sin \alpha} = X^\star \quad .. \quad .. \quad (31)$$

We then obtain : $\mathbf{U}_2 = \mathbf{E}^\star - jX^\star \mathbf{I}_1 \quad .. \quad (32)$

This equation is of the same type as (29). If we put :

$$M_{h,q}{}^\star = M_{h,q} \cos \Phi \quad .. \quad .. \quad (33)$$

then the equation (1) will again be valid except that in the present case the coefficients of the right hand side are starred symbols. Equations (2) and (4) will be multiplied by cos Φ. Denoting by an asterisk the various constants and the voltages X_6 and X_7 which have been multiplied by cos Φ, we then obtain a new system of equations, which is identical with the system (6) except that the constants have been given different values. Therefore it will not be necessary to repeat the calculations previously developed for the machine coupled to a rigid network, and we only have to determine how each of the expressions already obtained will have to be modified.

The following relations are easily found :

$$\sigma_{h,q}{}^\star = 1 - (1 - \sigma_{h,q}) \frac{\sin \alpha \cos \Phi}{\sin (\alpha + \Phi)},$$

$$T_{h,q}{}^\star = T_{h,q} \frac{\sigma_{h,q}{}^\star}{\sigma_{h,q}},$$

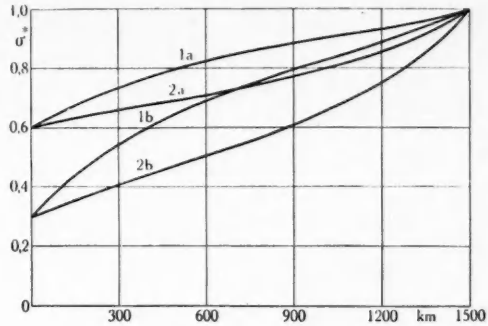
$$\Omega^{\star 2} = \Omega^2 \frac{\sin \alpha}{\sin (\alpha + \Phi)} \quad .. \quad .. \quad .. \quad (34)$$

$$A_h{}^\star = \frac{U_2}{E^\star} \frac{1 - \sigma_h{}^\star}{\sigma_h{}^\star}, \quad A_q{}^\star = \frac{U_2}{E^\star} \frac{1 - \sigma_q{}^\star}{\sigma^\star{}_q},$$

$$A^\star = \frac{U_2}{E} \frac{1 - \sigma^\star}{\sigma^\star}$$

In Fig. 7 the fictitious stray coefficient $\sigma^\star$ is plotted as a function of the line length for two values of α and σ. When the line length is 90 deg. (1,500 km.), $\sigma^\star$ is independent of the parameters α and σ. This is because the line with a 90 deg. length behaves as a Boucherot circuit ; when the voltage at the network end of the line is constant, the current at the machine's terminals is also constant. A variation in the excitation current will not then cause any change in the stator current. The machine will in this respect behave like a machine under no-load conditions, vibrating with a frequency $\Omega^\star$, therefore $\sigma^\star = 1$.

Power required for excitation. Angle-controlled regulation will first be considered, and for this the two values $\alpha = 30$ deg. and $\alpha = 60$ deg. will be used. If the nominal power of the machine corresponds to the natural power of the line, then 30 deg. will correspond to an unusually small synchronous reactance, while 60 deg. will represent a rather high value of this constant. A small value of α can also be obtained with a normal machine, by employing a nominal power which is greater than the natural power.



Curves 1 : $\alpha = 30$ deg. Curves a : $\sigma = 0{\cdot}6$.
Curves 2 : $\alpha = 60$ deg. Curves b : $\sigma = 0{\cdot}3$.

Fig. 7. Fictitious stray coefficient $\sigma^\star$.

The lowest permissible values for K_1 and K_{10} are determined by means of $K > |\text{ cotan } \vartheta_0|$ and equation (23) ; we then find for the two line lengths of 750 km. and 1,500 km. (45 deg. and 90 deg., respectively), the values given in Table II.

TABLE II. MINIMUM VALUES FOR K_1 AND K_{10}.

Line length	K_1 (1)		K_{10} (2)	
	$\alpha = 30°$	$\alpha = 60°$	$\alpha = 30°$	$\alpha = 60°$
750 km. ..	0	0·27	0	0·26
1,500 km. ..	0·57	1·73	0·50	0·87

(1) K_1 refers to an ordinary synchronous machine.
(2) K_{10} refers to a synchronous machine with excitation on both axes.

Thus with angle-controlled regulation an appreciable reduction of the factor K_1 when using the machine with excitation on both axes will only occur for very large pole-wheel angles. Furthermore, such a machine would involve considerable complications. The values of Table II are minimum values, with no allowance for dynamic stability ; and in practice these values should be very much higher.

The equation $\xi_5 = 1{\cdot}73\ \Delta\vartheta_1$ which is valid for $\alpha = 60$ deg. and a line length of 1,500 km. gives for an angular variation of 1 deg., $\xi_5 = 1{\cdot}73/57{\cdot}4$ (radians) $= 0{\cdot}032$. Therefore, for an angular variation of 1 deg. the excitation will have to be raised by at least 3·2 per cent. To take account of dynamic stability this value will have to be increased still further, and this shows that artificial stabilization requires an extremely high amount of power for excitation ; but this power should always be compared with that required when considering other methods suggested to improve stability.

The power for slip-controlled regulation is a more complicated function of the various parameters. The minimum values required can be determined with the aid of equations (18) and (23).

$$K_2 > T_h \left| \sigma^\star \frac{A_h{}^\star + \cos \vartheta_0}{\sin \vartheta_0} \right| = T_h \left| C_h \right| \quad .. \quad (35)$$

$$K_{20} > T_h \mid \sigma^\star (A^\star + \cos \vartheta_0) \mid = T \mid C \mid \quad .. \quad (36)$$

The two values of C_h and C for various values of α and σ are plotted against line length in Fig. 8. As long as C_h and C are positive, we are dealing with case α or β, and hence in principle a slip-controlled regulation is not required. The limit will be between 700 and 1,300 km., according to the values of α and σ. From (35) and (36) we see that C_h and C are a direct measure of the power required for slip-controlled regulation. Fig. 8 shows that the added complications of an excitation on the second axis will only be worth considering in the

case of very great line lengths and a large synchronous reactance. For $\sigma = 0{\cdot}3$ $T_h = T = 5$ *s* the values are given in Table III.

TABLE III.

Line length	K_2 *s*		K_{20} *s*	
	$\alpha = 30°$	$\alpha = 60°$	$\alpha = 30°$	$\alpha = 60°$
750 km. ..	0	0	0	0
1,500 km. ..	1·3	7·2	0·75	1·3

For a 1 per cent slip, $p\Delta\vartheta = 3{\cdot}14$. If $K_2 = 1$, this means that the exciter machine will have to more than treble the voltage on the pole-wheel winding. This shows that under extreme conditions a considerable amount of excitation power is required.

VII. INFLUENCE OF IMPERFECT REGULATION.

In practice the regulating equipment will not be able to fulfil the ideal conditions on which equations (11) and (20) are based. To take account of the effect of an imperfect regulation, equation (11) can be generalized as follows :

$$\xi_6 = (K_1 + pK_2)\, G\,(p), \quad .. \quad .. \quad (37)$$

assuming regulation is on one axis only. In the simplest case, where the imperfections can be expressed as a function of a single time constant, T, the factor G will be of the form :

$$G = \frac{1}{1 + pT} \quad .. \quad .. \quad (38)$$

Thus in (12) $Q(p)$ should be multiplied by the factor $1 + pT$. A quartic equation is then obtained, and the investigation shows that the quantities by means of which the influence of imperfect regulation can be determined are

$$\lambda_1 = T/T_h'^{\star} \text{ and } \lambda_2 = \Omega^{\star 2} T \,.\, T_h'^{\star}.$$

If these two ratios are both much smaller than unity, there will be no doubt as to the effectiveness of the artificial stabilization. Imperfect regulation has the effect of reducing the value of the critical angle ϑ_K. In principle, it can be said that when regulation is further away from the ideal case, the importance of slip-controlled regulation will be increased.

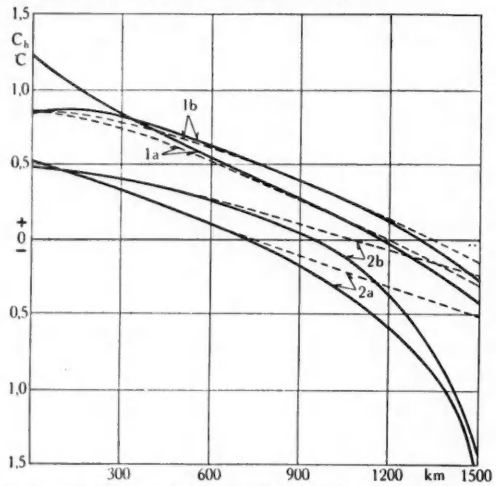


Fig. 8. The characteristic values C_h and C which are required to determine the power of slip-controlled regulation.

Curves 1 : $\alpha = 30$ deg. Curves 1 : $\sigma = 0{\cdot}6$. Solid lines : C_h.
Curves 2 : $\alpha = 60$ deg. Curves b : $\sigma = 0{\cdot}3$. Dotted lines : C.

VIII. COMPARISON WITH THE COMPENSATED ASYNCHRONOUS MACHINE.

The investigation of the problem of the asynchronous machine used for power transmission leads to results which are very similar to those obtained for synchronous machines. It has already been foreseen that the machine works with a zero slip under stationary conditions. With the synchronous machine it was also necessary to provide an excitation which would also depend on the amount of slip. Furthermore, it was found that in certain cases it would be desirable to fit another winding on the transverse axis. A machine of this kind is already similar to the particular type of asynchronous machine envisaged in this comparison.

In order to establish the common features of these two types it will be necessary to investigate more particularly the synchronous machine with regulation on both axes, and the air-gap voltage $\mathbf{E}_l$ will now be defined as the voltage which is situated behind the stray reactance σX. Then

$$\mathbf{E}_l = \mathbf{E} - j\omega L\,(1 - \sigma)\,\mathbf{I}_1 \quad .. \quad (39)$$

After a short calculation, taking account of (32) and (34), we find :

$$\frac{E_l}{E} \cos\vartheta_l = \sigma^{\star} \cos\vartheta + \frac{U_2}{E^{\star}}(1 - \sigma^{\star}) = C \quad (40)$$

Therefore (36) becomes :

$$K_{20} > T\,\frac{E_l}{E}\left|\cos\vartheta_l\right| \quad .. \quad .. \quad (41)$$

Now $p\vartheta = \Delta\omega$, where $\Delta\omega$ is the deviation from synchronous speed. If, moreover, ξ is the resultant of the voltage variations ξ_6 and ξ_7 (see Fig. 6), we obtain from (41) :

$$\xi > T\,\frac{E_l}{E}\left|\cos\vartheta_l\right|\Delta\omega \quad .. \quad (42)$$

This equation is identical with equation (26) developed in the article, " Stability of large asynchronous generators used for power transmission over long distances."* Taking into consideration the results obtained in this article, we obtain the following result : The synchronous machine with symmetrical regulation on both axes can always be stabilized by means of an angle-controlled regulation alone, if a corresponding asynchronous machine with constant excitation is stable under the same conditions. If slip-controlled regulation is necessary then the power required for this is the same in both cases. Fig. 8 shows that this statement is valid even for ordinary synchronous machines. The results of this investigation can also be interpreted as follows : Every synchronous machine is equivalent, in certain respects, to an asynchronous machine, and both have their stability limits. As long as stabilization is necessary only for the synchronous machine, angle-controlled regulation will be sufficient. If the asynchronous machine is also unstable, it will be necessary to resort to slip-controlled regulation.

Many other problems, such as the influence of saturation, of eddy currents in massive rotors, etc., still require investigation. The question of dynamic stability, which does not easily lend itself to mathematical treatment, has been investigated by means of model tests. With increasing difficulties in stabilization, the regulation problem compulsorily leads to a type of machine which closely resembles the compensated asynchronous machine. The constructional aspects of this problem will require further consideration in order to determine the most favourable conditions under which these two types of machine can be employed.

*Brown Boveri Mitteilungen, Vol. 33, No. 11, pp. 321-328, abstracted in *The Engineers' Digest*, Vol. 8, No. 8, pp. 261-262.

Automatic Control of Regional Heat Supply

By P. M. Brick. (From *Promishlennaya Energetika*, No. 8-9, 1946, pp. 7-9, 5 illustrations.)

In district heating manual control of the flow conditions is possible only in a minority of cases, and automatic control should be made the general rule.

Since thermal and pressure regulators so far produced in the U.S.S.R. have failed to be adaptable to the characteristics of thermal networks, the Research Laboratory ORGRES, under the direction of the author, has developed two types of regulators capable of carrying out all operations necessary for hydraulic control. After subjecting these new designs to every kind of test, in which they were found to satisfy all service requirements, they were released for mass production.

Assuming a two-mains system, which is the type generally met in the U.S.S.R., to which individual consumers are directly connected, the following control operations are necessary to maintain normal circulation :

(a) Quantity control (topping up) of the water supply to the mains, relative to the outflow, in order to keep the neutral point pressure in the system constant. This protects the system from inadmissible pressures in local branch systems, and from the formation of vacua or air locks at raised points.

(b) Control of the hydraulic resistance in the return pipes of feeders in local systems for high buildings, or buildings on high ground (i.e., support control).

(c) Control of the hydraulic resistance of the supply pipes of feeders in local systems, or of groups of such systems, to maintain the constant pressure head (i.e., the pressure difference between supply and return main) at points of connection to the grid.

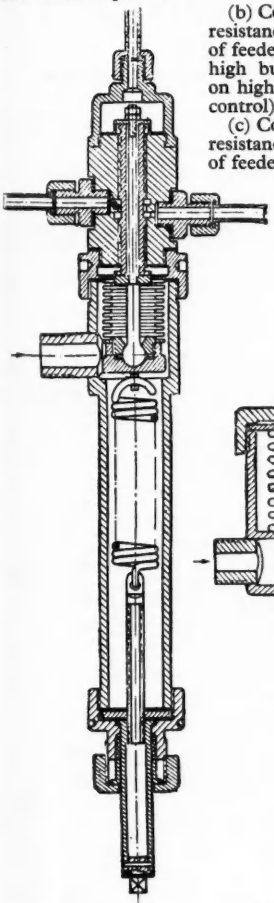


Fig. 1. Universal pressure relay type URD-3.

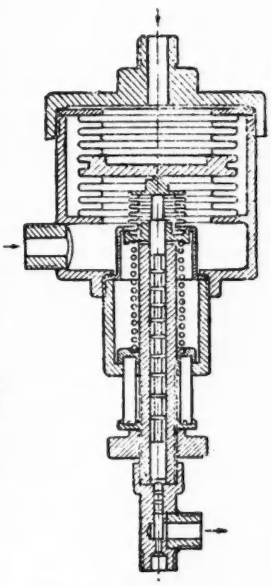


Fig. 2. Double-impulse relay of the topping-up regulator.

From an investigation into the question which are the most suitable types of regulators, the following standards have emerged :

(a) Indirect-action regulators for controlling the supply to the regional central station, and the head and pressure in local systems of high capacity, or in groups of such systems. This type can be made with a high sensitivity not influenced by variations in the working conditions. A disadvantage of the type, however, is its rather complicated design and the necessity to provide a separate source of power.

(b) Direct-action regulators for controlling pressure head and pressure in small-scale local systems. This type is simple in design and reliable, although working with a lower sensitivity.

The tasks specified above are allotted to representative types of one of the two following series of designs, viz. : (1) the Universal Pressure Regulator URD (indirect action) ; (2) the RPR-Regulator for maintaining constant supply, and (3) the direct-acting RP-Regulator for the support.

The Universal Pressure Regulator works on the principle of the throttle flap, and consists of a relay device, more particularly of the Universal Pressure Relay, type URD–3 (Fig. 1), or the relay RPD (Fig. 2), and a controlling element, which in this case is a single-seat valve, with a membrane-type servo-motor.

The operating medium is water at a pressure of 1·5 to 4 atmospheres and a temperature not higher than 30 to 35 deg. C., free of suspended matter. The sensitive element of the relay URD–3 is a pair of metallic bellows (" sylphon "), and the actuating element is a slide valve.

Depending on the value of the controlled parameter (pressure or pressure head), and the spring rate, or tension, the slide valve is in equilibrium in a certain position, thereby partly covering the communicating aperture, and thus producing a certain pressure of the working medium in the controlled system which, in turn, determines a certain position of the regulating valve stem. The theory of the operation of this regulator was published by the author in *Teplosilovoe Chosjaistvo*, Nov. 2, 1940.

It should be noted, however, that the design of the regulators now in mass production, while based on the same principle, has been substantially improved, as, for example, by the use of metallic bellows as sensitive element instead of the porting edges of the valve of the original construction. This resulted in a much increased sensitivity and reliability, and greater independence from the purity of the water.

Also, the sensitivity of the relay was increased, thus reducing the total error of the regulator to 0·1 or less atmospheres (depending on the characteristic of the controlled section). The use of springs instead of weights reduced the bulk of the devices without appreciable increase of error in the regulators.

In large diameter valves the direct action of the relay on the servo-motor is unfavourable owing to the low adjustment velocity of the valve spindle, and that is why, in such cases, an " accelerator " (see Fig. 3) is inserted between relay and servo-motor, enabling high adjustment velocities to be obtained.

The Universal Regulator combined with the URD–3 Relay can discharge the following duties :

(1) Those of a constant pressure regulator with return action for governing the supply to the central heating plant (Fig. 3), the controlled parameter in this

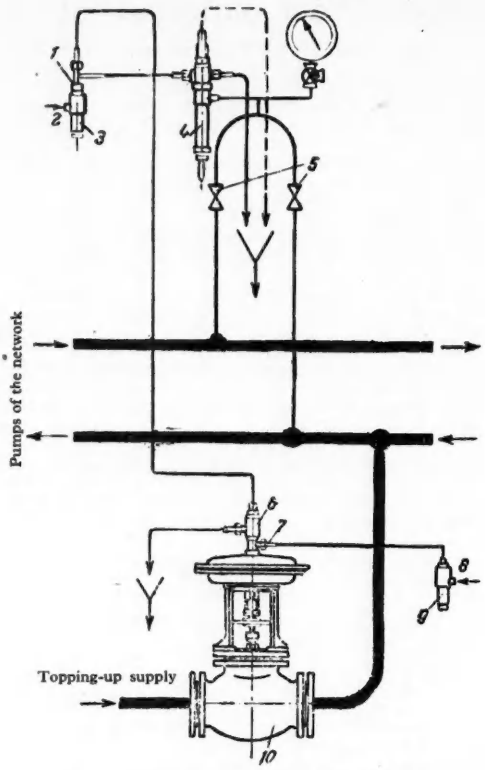


Fig. 3. **Arrangement of the topping-up regulator.**
(1) Throttle (internal) ; (2) Water pipe ; (3) Filter ; (4) Pressure Relays ; (5) Regulating valves ; (6) Accelerator ; (7) Throttle (internal) ; (8) Water pipe ; (9) Filter ; (10) Topping-up valve. In the figure : left-hand side, Pumps of the net. Bottom : Topping-up supply.

case being the pressure in the neutral point of the thermal network.

(2) Those of a regulator for the pressure head in heating and ventilating systems, the controlled parameter being the pressure difference between supply and return mains.

(3) Those of a pressure regulator with forward action, for the maintenance of minimum pressure in heating and ventilating systems, the controlled parameter being the pressure in the return main of the local system.

The regulator URD may, furthermore, be used for all similar purposes connected with the maintenance of pressures in any type of water or steam supplying system.

Where thermal networks operate with considerable fluctuations in flow conditions, the pressure in the neutral point cannot be kept constant. It is then necessary to raise it in proportion to lowered circulation, in order to obviate the formation of vacuum locks in raised parts of local systems. This is possible by the use of the RPD Relay. This relay varies the water pressure in the controlled system depending on two parameters, viz. : the pressure in the return main, and the pressure difference between the sections in front of, and behind, the throttle flap inserted in the said main.

The constant consumption regulator RPR (Fig. 4) works on the following principle. The pressure of the water entering the regulator and acting on the valve

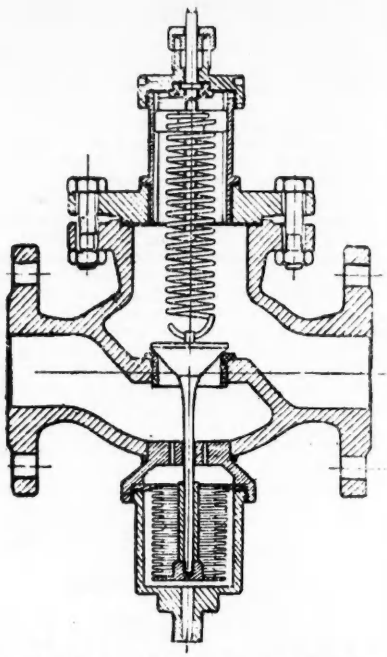


Fig. 4. **Constant consumption regulator RPR.**

from below tends to lift the latter. The same pressure, however, is acting on the sylphon (whose area is equal to that of the valve) from above and tends to depress the valve with the same force.

Thus the regulator is relieved from the water pressure in front of it.

The pressure of the water behind the regulator, that is, in the supply main of the local system, acts on the valve from above, whereas the pressure in the return main acts on it through the intermediary of the syphon from below. The difference between these opposing pressures is balanced by a spring the initial tension of which is adjusted by a screw, according to the pressure difference required, between the supply and return mains. Where the hydraulic characteristic of the local

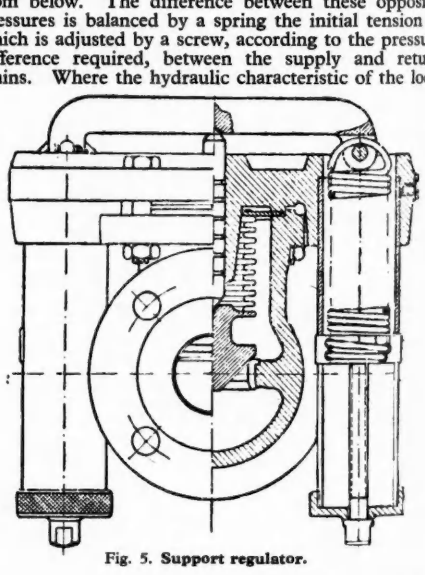


Fig. 5. **Support regulator.**

system remains steady, the regulator works with a negligible non-uniformity, while small oscillations of the pressure head do not cause the water consumption to change by more than 3 to 4 per cent. Thus there is practically no range of insensitivity of the regulator, as it is protected against onrushes of steam.

Yet, when the flow characteristic of the controlled section changes, so does the magnitude of the pressure difference change accordingly. This renders a regulator of this type unsuitable for groups of local systems which may alternatively be taken off the thermal network (e.g. when working with individual admission). In this case the regulator URD will serve.

The working principle of the support-regulator RP (Fig. 5) is as follows : due to the working areas of valve and syphon being equal, the regulator is fully relieved from the pressure of the water behind it, i.e. from the pressure in the return main of the thermal network. The water pressure to the regulator, or the pressure in the return pipe of the local system, acts on the valve from below and tends to lift it. This force is balanced by springs whose initial tension is adjusted according to the required pressure in the local system. The resulting non-uniformity of these regulators is small and fluctuates, according to the characteristics of the controlled section, within limits of 0·05 to 0·1 atmos.

The regulator is not very sensitive to changes of the characteristic in the controlled section. Yet its construction becomes so cumbrous for large diameters that the type URD will be preferred when consumers of big powers are connected.

In conclusion, it should be remembered that where thermal networks supply heating and ventilating systems only, automatic control is redundant where heat flow is concerned, because centralized manual control can cope with this duty. The necessity for automatic control of heat flow only arises where consumers are to be supplied with hot water.

AUSTRALIA

A Critical Temperature Range in the Plastic Deformation of Plywood

By H. G. Higgins. (From *Journal of the Council for Scientific and Industrial Research of the Commonwealth of Australia*, Vol. 19, No. 4, November, 1946, pp. 455-462, 4 illustrations.)

I. INTRODUCTION.

The differences between the elastic properties of wood in three directions—longitudinally, tangentially, and radially—have received detailed study. Similar differences in plastic behaviour must occur along these three axes, making extensive modifications necessary in the application to wood of conceptions of plasticity developed for isotropic substances.

The effect of temperature on plastic deformation is of practical importance in the fabrication of plywood by the hot press technique. For this reason plywood was chosen as the material for the present study, although its manner of construction adds to the inherent complexities of the wood substance itself.

2. MATERIALS AND APPARATUS.

Plywood consisting of three plies was used. The veneer was rotary-cut hoop pine of nominal thickness $\frac{1}{8}$ in. and it consisted of closely matched material from the same log. It was bonded together with a phenol-formaldehyde film adhesive under a pressure of 50 lb./sq. in., for eight minutes at 145 deg. C. Specimens 4 in. by 4 in. were cut from each panel, and for each series of tests, specimens were used from the same panel.

A modified "Carver" laboratory press was used in the experiment. The platens were heated electrically, and the temperature was controlled by means of a bimetallic strip thermostat inserted in each platen, and used in conjunction with a hot-wire vacuum switch.

3. PRELIMINARY TESTS AT EQUILIBRIUM MOISTURE CONTENT.

The thickness of each specimen was measured with a micrometer gauge, each determination being the mean of eight measurements—one in each corner and one near the centre of each side. The moisture content of the specimens was in equilibrium with atmospheric conditions in the laboratory at the beginning of the test. The specimens were subjected to a series of pressures ranging from 200 to 1,200 lb./sq. in. and at temperatures ranging from 120 deg. to 200 deg. C. Before applying the load each specimen was left in the press for two minutes with the platens closed. This should be sufficient time to bring the temperature of the whole specimen to within about one degree of the platen temperature. The load was then applied and maintained for five minutes, after which the specimen was removed from the press. The temperature of each platen was read at minute intervals from the time of insertion of the specimen. The thickness of the specimen was determined as before immediately after removal from the press. The results are shown in Table I, in terms of residual deformation, which is the difference between the mean thickness before and after pressing.

TABLE I. Residual Deformations (in Inches).

Series of Tests	Pressure (lb./sq. in.)	Temperature (deg. C.) 120	140	160	180	200
Preliminary Series (at equilibrium moisture content initially)	200	·0027	·0022	·0019	·0018	·0019
	400	·0036	·0040	·0033	·0028	·0034
	600	·0068	·0043	·0079	·0048	·0079
	800	·0251	·0082	·0162	·0096	·0322
	1,000	·0438	·0218	·0188	·0212	·0497
	1,200	·0495	·0404	·0426	·0549	·0609

Each figure represents the difference between the means of eight determinations of initial and final thickness.

4. SECOND SERIES OF TESTS.

The preliminary series of observations were repeated using a somewhat more refined technique. It had been observed that the moisture content of the first series of specimens had varied considerably owing to changes in the weather, and in the second series all the observations were made when the moisture content of a control specimen kept with the rest was between 7 and 8 per cent, as determined by weighing, oven-drying, and re-weighing. In addition a simple device was used to ensure that the specimen was situated directly over the ram of the press. Apart from these modifications the same procedure was adopted as for the preliminary tests. Results are shown in Fig. 1.

5. TESTS ON OVEN-DRY MATERIAL.

Examination of Fig. 1 revealed a minimum in the temperature-residual deformation curve for each load. To explain this the tentative hypothesis was adopted that the lower rate of drying at lower temperatures allowed the moisture to exert a plasticizing action on the wood for a longer time. For valid results therefore, it was evident that the moisture content had to be controlled for the duration of each test. The most

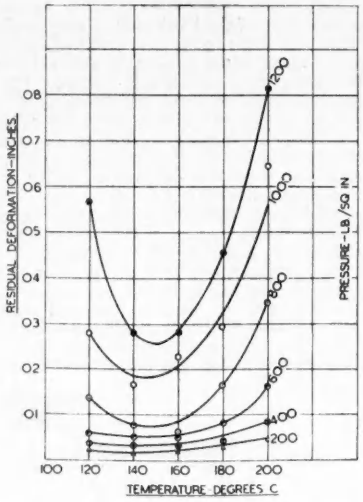


Fig. 1. Specimens initially at 7-8 per cent equilibrium moisture content.

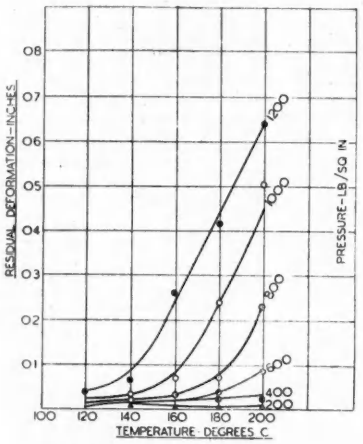


Fig. 2. Oven-dry specimens.

convenient way of doing this was by using oven-dried specimens, and a new series of tests was carried out. The specimens were kept for two days in an oven maintained at 105 deg. C. Directly after removal and before putting in the press, the thickness of each was measured ; the rest of the procedure was similar to that adopted in the previous series of tests. The results are plotted in Figs. 2 and 3.

6. EFFECT OF MOISTURE ON PLASTICITY.

Reference to Figs. 1 and 2 reveals that even a small initial amount (7-8 per cent) of water greatly increases the plastic flow. The minimum in the temperature-residual deformation curve is eliminated in Fig. 2, deformation rising throughout with increasing temperature. It appears that the plasticizing action was exerted by the moisture in the form of steam, since the load was not applied until the temperature rose above the boiling point. At the higher temperatures most of the steam was driven off apparently before the load was applied.

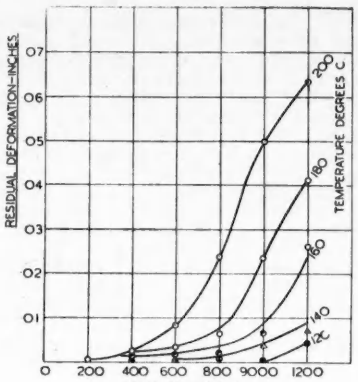


Fig. 3. Pressure-deformation curves for oven-dry specimens.

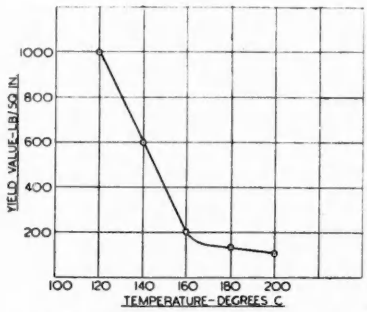


Fig. 4. Yield values for oven-dry specimens.

7. EFFECT OF TEMPERATURE ON PLASTICITY.

Fig. 2 shows the effect of temperature on the residual deformation of the plywood for various loads and it is evident from the differences in deformation at the two extremes of temperature that this range is highly critical. That this is particularly so at higher loads may be seen from Fig. 3, where the same data are plotted in the form of pressure-deformation curves, deformation rising sharply as the pressure increases.

If the yield value is taken as the point at which the pressure-residual deformation curves for various temperatures approach the load axis, a curve can be drawn showing the effect of temperature upon yield value. This takes the form shown in Fig. 4, the yield values being taken as the pressures corresponding to the points in Fig. 3 at which the smoothed curves intersected the + 0·0005 in. abscissa, since very small residual deformations occurred even at low loads. It can be seen that with rising temperature the yield value declines rapidly from 120 deg. to 160 deg. C., above which it remains low. Temperatures in the vicinity of 160 deg. C. may therefore be regarded as critical in the mode of plastic deformation, since the disappearance of yield value represents a fundamental change in the plastic behaviour.

Yield values will almost certainly vary with the direction and rate of loading, as well as with the species and other factors. However, the critical temperature when the yield value vanishes or becomes very small may be largely independent of these factors, and may be dependent primarily on the nature and properties of the lignin which binds the cellulose fibres.